AN ABSTRACT OF THE THESIS OF

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Title: First-Year Effects of Broadcast Burning on Soil Infiltration and Wettability in Southwest Oregon

Abstract approved: ______________________________

Soil infiltration and wettability measurements during the first year following a broadcast burn in the Siskiyou Mountains of southwest Oregon, have illustrated the magnitude of the effects of light-to-moderate intensity burning on hydrological soil properties. A prescribed fire near White Creek in late spring significantly reduced soil infiltration for 4 months following the burn, but infiltration rates below the maximum 100 year precipitation event for the area were not observed. The lowest infiltration rate recorded on logged and burned soil was 5.3 cm/hr (2.1 in/hr), but 94% of all the observations ranged between 9.0 and 11.4 cm/hr (3.5 and 4.5 in/hr). Infiltration rates recorded on logged and unburned soil were greater than 11.2 cm/hr.

Broadcast burning caused hydrophobic substances in the litter and duff layers to become volatilized, subsequent condensation of these substances on soil particles located in the 0-5cm depth of

soil. A total of 25% of the exposed mineral soil surface in the burned section was water repellent 9 days after burning, but this was reduced to 6% within five months. Some naturally-occurring water repellency existed in the unburned condition, yet the greatest percentage recorded was only 1% in August, when soils were at their driest.

In assessing the wetting difficulties of a soil sample, the measurement of an apparent liquid-solid contact angle was more consistent than obtaining water drop penetration times. The penetration time of a water drop is dependent on the wetting difficulties and pore geometry of the soil directly beneath it, therefore measurements were highly variable for any one soil sample.

Regression models correlated infiltration rates with soil contact angles in the burned section. Association was strongest (r^2 = .93) for infiltration rates obtained on unsaturated soils in which attraction forces between the soil particles and water molecules predominate. Since this attraction is inversely related to the liquid-solid contact angle, infiltration rates decreased with increases in the liquid-solid contact angle.

During the summer, residual vegetation in the unburned section significantly reduced percent soil moisture below levels recorded in the burned condition. Increased precipitation and lower evapotranspiration demands, combined with rapid growth of resprouting and invading vegetation in the burned section during early fall, probably led to soil moisture becoming nearly equal in both conditions by mid-fall.

Supplemental hydrological soil measurements, collected 33 days after a moderate intensity broadcast burn at Shan Creek, did not markedly differ from those obtained 44 days after the light-to-moderate intensity burn at White creek. Although Shan Creek did have a greater percentage of water repellent soil (52% vs. 12%), there was not a significant difference between infiltration rates obtained at both sites.

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First-Year Effects of Broadcast Burning on Soil Infiltration and Wettability in Southwest Oregon

by

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INTRODUCTION

The Problem

Since southwest Oregon produced about one third of Oregon's harvested timber from 1970 to 1974 (Bassett 1979), it should be a focal point on research concerning reforestation. Inadequate or delayed restocking of harvested areas has resulted in reduced harvest levels in the region (BLM, 1978 and 1979), thus threatening the economic stability of southwest Oregon.

Efforts to improve reforestation practices are dependent on a thorough understanding of the effects of site preparation on the soil resource. While many other factors contribute to reforestation problems, drastic alteration of preharvest physical soil conditions by logging and broadcast burning may cause surface soil erosion, followed by inadequate seedling survival.

Broadcast burning has been widely utilized as an inexpensive and efficient site preparation technique, especially on steep slopes where mechanical treatment is impractical. It is well suited to mountainous areas of southwest Oregon, where reducing fire hazard, controlling competing vegetation, and exposure of bare soil for planting are beneficial characteristics (Wells, et al., 1979). How effective broadcast burning is in providing these characteristics without seriously altering the physical, chemical, and biological properties of the soil depends on many site and climatic conditions unique to each area of consideration.

Many studies have been conducted in western Oregon that give insight regarding the effects of broadcast burning on the physical soil resource, although little research has been done in southwest Oregon until recently.

Variability in climatic conditions and soil type in southwest Oregon limits the usefulness of available literature. A recent study has shown precipitation in the region to range from 20 to 160 inches per year and 3 to 15 inches during the growing season (May to September). The last half of June, all of July and August, and the first half of September tend to be much drier in southwest Oregon than the remainder of western Oregon. Typical values of total precipitation during this time period range from only 1.5 to 5.0 inches with only a few storms providing the total amount (Froehlich et al., 1982). Due to this dry climatic condition, vegetation is not as abundant in comparison to the Coast Range. The soils are shallower, contain less organic matter, and can become exceedingly droughty during the summer (Hobbs et al., 1980).

Past investigations relating to broadcast burning and its effects on the physical soil resource have identified burning intensity as the main independent variable which influences changes in soil texture, specific surface, structure, bulk density, porosity, soil moisture, apparent liquid-solid contact angle, infiltration, runoff and sediment loss (Wells et al., 1979). This study will concentrate on soil moisture, apparent liquid-solid contact angle, and infiltration.

Objective

To determine whether broadcast burning in late spring alters soil infiltration, wettability, and moisture during the remainder of the year on a site with steep slopes and skeletal soils in southwest Oregon.

CHAPTER II

REVIEW OF RELATED LITERATURE

The Intensity of a Broadcast Burn

The magnitude of the effect of fire on the soil is proportional to the heat penetration into the soil. This is determined by the fire intensity. Intensity is a function of the maximum temperature reached as well as the duration of the temperature at a certain point over time. (Boyer and Dell, 1980).

The intensity of a broadcast burn at a given site is usually classified as severe, moderate or light (Wells, 1971). Since a fire needs dry fuel and oxygen to burn, the intensity depends on size, type, amount, and compaction of fuel, and on fuel moisture content. It further depends on other conditions such as wind, slope, temperature, and humidity. The intensity would increase with larger amounts of medium size, dry slash, spaced to allow adequate air ventilation. While high windspeed and steep slopes may increase the rate of spread, the amount of heat transmitted to the soil at any given point would be greatest with lower windspeed, moderate slope percent, high air temperature and low humidity (Martin and Brackebusch, 1974).

The concentration and spacing of available fuel for a broadcast burn can be highly variable. Therefore, intensity of the burn for the entire site is normally discontinuous. Sites chosen for past research in western Oregon have generally had light to moderate intensity burns with occasional spots of severely burned soil that typically comprise less than 10% of the total area burned. Only severely burned soils created physical soil conditions that resulted in surface erosion or were detrimental to the survival of natural or planted regeneration (Cleary et al., 1978; Dyrness et al., 1957; Boyer and Dell, 1980; Austin and Baisinger, 1955; Morris, 1970).

Utilizing descriptive terms mentioned in work by Morris (1970), Dyrness and Youngberg (1957) and Ralston and Hatchell (1971), Boyer and Dell (1980) described the various levels of fire intensity:

<u>Lightly burned</u>: The surface duff layer is often charred by fire but not removed. Duff, crumbled wood and other woody debris partly burned, logs not deeply charred.

In clearcuts: Surface temps of <200°C (390°F).
In underburns: Surface temps of <180°C (350°F).
Surface temps of 177°C produced soil temps of 71°C @ 2.5 cm.

<u>Moderate burn</u>: Duff, rotten wood or other woody debris partially consumed or logs may be deeply charred but mineral soil under the ash not appreciably changed in color.

In clearcuts: Surface temps of 200°C-500°C (390°F-930°F).
In underburns: Surface temps of 180°C-300°C (350°F-590°F).
Surface temps of 400°C produced soil temps of 177°C @ 2.5 cm.

<u>Severe burn</u>: Top layer of mineral soil significantly changed in color, usually to reddish color; next one-half inch blackened from organic matter charring by heat conducted through top layer.

In clearcuts: Surface temps of >500°C (930°F).
In underburns: Surface temps of >300°C (590°F).
Under piles: Surface temps of >650°C (1200°F).
Wildfire: Surface temps of >760°C (1400°F).
Surface temps of 500°C produced soil temps of 288°C @ 2.5 cm.

Broadcast Burning and Physcial Soil Properties

Infiltration

Infiltration is the process of water entry into the soil surface. Infiltration rate is the flux passing through the surface and flowing into the profile, and infiltration capacity is the maximum flux which the soil surface can absorb when maintained in contact with water at atmospheric pressure (Hillel, 1971). In forested areas the process of infiltration includes detention storage and absorption of water by the forest floor.

Infiltration of water into an unsaturated soil is in response to capillary and gravitational forces (Gray, 1970; Hillel, 1971; Satterlund, 1972). Gravitational force acts in the downward direction, while capillary forces act laterally as well. Capillary force is the result of greater adhesive forces between the solid soil pore surfaces and water than cohesive forces of the water molecules themselves (Hillel, 1971). The force exerted is a function of the slope of its meniscus determined primarily by the capillary radius and the degree of attraction (contact angle) between the water and the soil pore surfaces. The infiltration rate is initially controlled by capillary forces when water is first applied to an unsaturated soil. As water penetrates deeper into the soil profile and the soil water content increases, gravitational force begins to dominate. This continues until the infiltration rate is practically equal to the saturated hydraulic conductivity, given that the soil profile is homogeneous and structurally stable.

The initial infiltration rate for a storm on an unsaturated soil and the final infiltration rate differ. The infiltration rate decreases due to the average suction gradient continually decreasing as the infiltrating water penetrates deeper into the profile (Hillel, 1971). Other factors contributing to this difference are changes in the surface macro and micro-structure from raindrop impact, the swelling of colloids, air entrapment, and the plugging of pore space with fine silt and clay particles (Horton, 1940). For the purpose of this study, infiltration capacity and final infiltration capacity are synonymous.

Fire influences infiltration by changing variables upon which infiltration is dependent: characterisitics of the forest floor, soil surface area, structure, porosity, apparent liquid-solid contact angle, and solute concentration of the infiltrating water. Infiltration can be expected to decrease when fire is of high intensity and the organic covering of the soil is completely consumed. Aggregates are dispersed by rainfall on exposed soil and pores become clogged with fine particles so that bulk density increases and porosity decreases (Arend, 1941; Sampson, 1944; Beaton, 1959; Hussain et al., 1969), or hydrophobic substances may increase the liquid-solid contact angle and impede water entry into the soil (DeBano and Krammes, 1966, Dyrness et al., 1976; Reeder and Jurgensen, 1979). Other studies in brushfields and nonforestland reported no change in infiltration rate or capacity due to intense burning (Scott and Burgy, 1956; Scott, 1956). Tackle (1962) reported an initial decrease in infiltration due to slash burning, but after four years favorable plant growth apparently increased infiltration above unburned areas.

When the rate of water applied to the soil surface exceeds the infiltration rate of the soil, surface runoff and erosion occurs. This effect is attenuated by litter and duff presence. These layers absorb water and extend the time over which infiltration can occur, as well as present a barrier to the overland flow of water and detached soil particles which tend to decrease surface runoff and erosion. In central Idaho, Bethlahmy (1967) found that runoff and erosion were greater on southwest than on northeast exposures. Bare soil comprised 28% of the southwest exposure compared to only 0.9% of the northwest.

With low rainfall intensities and high infiltration capacities overland flow is unlikely in western Oregon, but disturbance from forest management activities that result in severly burned or compacted soils may lend to appreciable sheet or rill erosion. A severe burn will seriously reduce litter and duff reservoirs as well as affecting soil properties. Intense fire has been reported to increase runoff and/or erosion (Connaughton, 1935; Holland, 1953; Rowe, 1955; Hussain et al., 1969), whereas low intensity fires, where litter is not completely consumed, have been qualitatively described to have little or no effect on surface runoff and erosion.

Soil Moisture

Fire can affect soil moisture in two ways. An immediate effect would be a change in the water-holding capacity of the soil, due to intense heat, consumption of organic matter, and alteration of physical soil properties. Water-holding capacity of the soil, the difference between moisture retained at 1/3 and 15 atmosphere pressure, usually is not seriously affected by fire, but intense burning may decrease water-holding capacity in the surface inch (Austin and Baisinger, 1955).

A second effect of fire on soil moisture occurs as a more time dependent result. By reducing the amount of residual vegetation occupying a site, soil moisture is not as heavily depleted during a dry season such as summers in southwest Oregon. This can be a favorable situation when considering the survival of planted regeneration. To what extent residual vegetation is reduced and which species of brush occupy a site after burning depend on the extent of disturbance or fire intensity (Steen, 1965).

In 1967, William E. Hallin researched the depletion of soil moisture in a timbered area versus a cutover area that was burned 2 years before measurements were initiated. His site was located in the South Umpqua drainage area. Medium to dense vegetation on the cutover was largely Rubus leucodermis, Ceanothus integerrimus, and Ceanothus velutinus. He found rapid depletion of soil moisture during the dry season (May through September) to be nearly equal for both conditions at depths of 16 and 46 cm. Reduction of soil moisture was slightly greater for the timber plot at a depth of 92 cm. The results emphasize the need for control of competing vegetation, expecially species of Ceanothus, before planting takes place. Broadcast burning has been used to accomplish this goal, but a study by Morris in 1970 indicated a stimulation of the establishment of Ceanothus due to slash burning on a site in the southern Cascades. Kraemer and Hermann reported in 1979 that Ceanothus competed better on low fertility sites. These studies indicate that broadcast burning may not be as effective in controlling competing vegetation as previously thought. Stimulation of moisture depleting species, such as Ceanothus, needs to be investigated on potentially droughty sites.

Soil Wettability

Not all soils readily absorb water; some, in fact, tend to repel water. Leachates from resinous leaves and fungi are known to contain hydrophobic substances such as substituted phenols, aliphatic hydrocarbons, and long-chained amines (Savage et al., 1972). These substances may coat soil particles when leached from the litter and duff layers of the forest floor. This coating causes water to remain or to "ball-up" on the surface, because the attraction between water molecules is greater than that between water and the solid surface. In this way, the apparent liquid-solid contact angle is increased (Figure 1) (DeBano et al., 1967).

Naturally occurring repellency often results from microorganism populations, particularly fungal mycelia. White fungal hyphae were consistently found in the litter layer of white pine, aspen, and sugar maple stands which had a naturally occurring water repellent mineral soil layer. This phenomena was observed by Reeder and Jurgensen (1979) on sand to loamy sand soils in the upper peninsula of Michigan. It has also been observed in sagebrush litter (Britton, 1979), and soil nonwettability caused by fungi appears to be widespread with a strong association connected to sandy soils (Savage et al., 1969).

Textural properties of the soil, particularly those relating to total surface area, seem important in determining the severity of the repellency. Thicker water repellent layers are usually found in coarse textured soils, while in the finer textured soils both thickness and the intensity of the water repellent layer is reduced (DeBano, 1966). The total surface area of a finer textured soil is much greater than that of a coarse textured soil, resulting in a reduced probability that all the soil particles will become completely coated by hydrophobic substances.

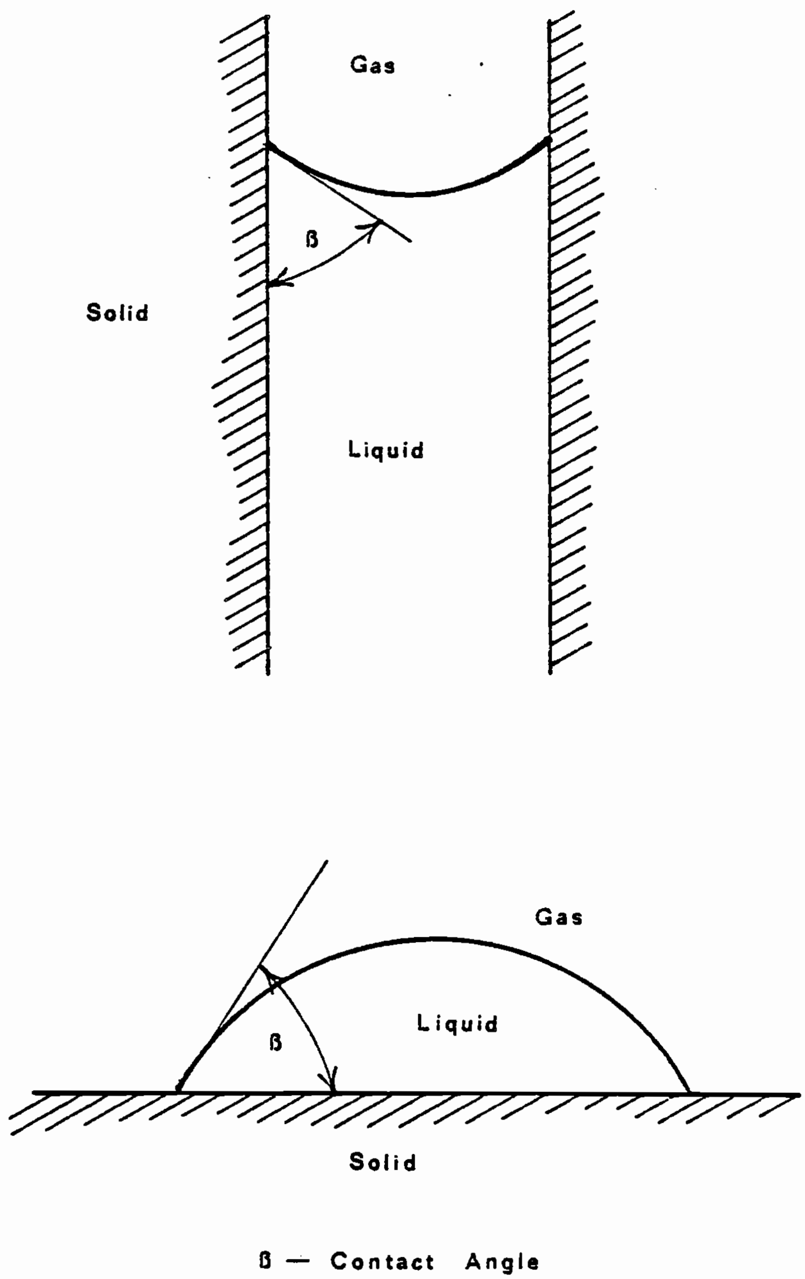


Figure 1. The contact angle of a meniscus in a capillary tube and of a drop resing upon a plane solid surface.

Empty soil pores are also needed for the volatilized substances to move into the soil, a condition which is likely to occur in a coarse textured, droughty soil (DeByle, 1973).

The water repellent effects may be intensified by burning, which volatilizes and perhaps polymerizes hydrophobic compounds and allows them to diffuse into the soil, where a decreasing temperature gradient results in their condensation on soil particles. As heat becomes more intense and fire consumes more of the litter layer, more volatilization occurs and hydophobic compounds will move deeper into the mineral soil. The effect is related to litter temperature attained during the fire, and the duration of the temperature. Temperatures initiating water repellency appear to be in excess of 250°C (482°F) for 10 minutes (DeBano et al., 1976). Temperatures in excess of 280°C (536°F) have been found to destroy water repellency (Scholl, 1975; Savage, 1974; DeBano and Krammes, 1966).

Fire intensity determines where and to what extent water repellency is induced or increased. In a light intensity burn, only the naturally occurring water repellency may exist. A medium intensity burn may enhance natural water repellency and induce small spots of hydrophobic conditions, but it is likely that this condition will be restricted to the soil surface. A high or severe intensity burn will consume all of the litter layer and may create a water repellent layer inches below the soil surface due to deeper distillation of hydrophobic compounds and the destruction of surface water repellency by intense heat (DeBano et al., 1967). However, it is unusual to find water repellency occurring deeper than 20 cm, and it is typically found at shallower depths (Wells et al., 1979).

Fire-induced water repellency has been observed to be a temporary condition. Broadcast burning of larch/Douglas-fir logging residues on a soil with high clay content in western Montana caused a temporary increase in the percentage of mineral soil samples found repellent after fire. This repelling, however, was lost within a couple of years (DeByle, 1981). On a coarser textured soil, Dyrness (1976) found a one-to nine-inch thick repellent layer persisted for five years following a wildfire in a lodgepole pine forest in the Oregon Cascades.

Severe intensity burns are common under piled slash due to the effect fuel loading has on the maximum temperature and duration of the burn. Under a burned slash pile, Vogl and Ryder (1969) found water repellency to last for 15 years.

The exact reason for the loss of water repellent substances has not been determined. Some possibilities are leaching, destruction by freezing conditions, or by microbial action. In short, processes which cause soil weathering would seem to be involved in the removal of a repellent layer. This could be an important factor when considering a site preparation technique in an area that experiences a slow weathering process. An example of this might be an alpine or arid environment.

The hydrologic significance of water repellent soil can be extreme. The most important consideration is that of reduced infiltration rates. Gilmore (1968) examined infiltration rates on several Australian soils and found lower infiltration rates associated with soils coated with organic films. The increased contact angle of wetting hindered water entry into the soil surface. Meeuwig (1971) also observed soil water repellency to impede infiltration beneath pine litter in the granitic soils of the Carson Range of the Sierra Nevada.

Perhaps a major concern regarding water repellency and infiltration rates may occur when a high intensity burn results in a water repellent layer a few inches below the soil surface. This layered arrangement allows incoming rainfall to infiltrate only to a limited depth before the wetting front reaches the water repellent layer. After the thin mantle above the water repellent layer becomes saturated, surface runoff may move it to a nearby stream. The result would be reduced site quality, and sediment loading in the stream system.

Soil water repellency is becoming a more significant issue with forest managers. Most of the past research has been conducted by DeBano at the San Dimas Experimental Forest in southern California. The chapparal vegetation that inhabits that area represents a considerably different environment than forested areas of western Oregon. However, this pioneering research has established useful techniques to begin to quantify effects of water repellency in western Oregon.

CHAPTER III

DESCRIPTION OF THE STUDY AREA

Location and Topography

The White Creek site is part of the much larger White Creek watershed, located in Josephine County, Oregon about 5.5 miles southeast of Selma in the SW 1/4 of Section 23, Township 38 South, Row 7 West, Willamette Meridian (Figure 2). The study area is owned by the Bureau of Land Management (BLM).

The total area of the site is about 7 ha with a northeast aspect. The mean elevation is approximately 792.5 meters (2600 feet) above sea level and slope percent ranges from 50 to 80 percent, with an average of about 65 percent.

Climate

The climate of southwestern Oregon is dominated by the Pacific Ocean. The area mostly has short, cool, moist winters and long, warm dry summers. Dry continental winds that influence the area during growing seasons can directly or indirectly lead to regeneration problems after forest harvesting. The soils are drier in the rooting zone than the wilting point for grass for more than 45 consecutive days a year (deMoulin et al., 1975).

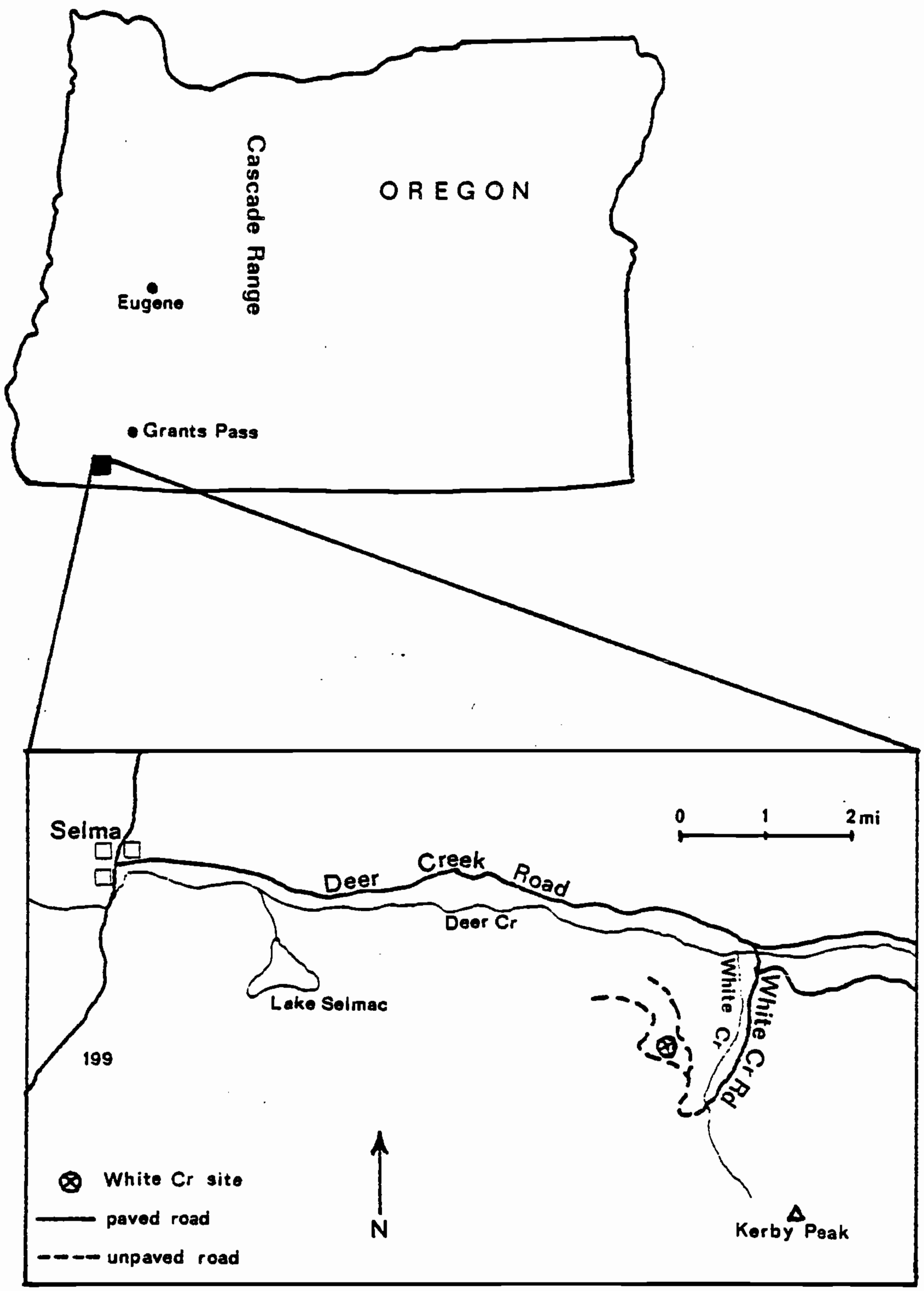


Figure 2. Location of the study area in the White Creek watershed.

From November through May, long duration frontal storms moving inland across southwestern Oregon account for 85 percent of the region's annual precipitation. Most of the storms that occur during this period are of long duration, low to moderate intensity rainfall, and are associated with low pressure areas originating over the ocean.

The annual precipitation at the White Creek site ranges from 114 to 127 cm (45 to 50 inches) and the value for the growing season (May through September) ranges from 15 to 18 cm (6 to 7 inches) (Froehlich et al., 1982). Although most precipitation occurs as rain, light to moderate accumulations of snow, due to the elevation, is common to the site. The majority of the rainfall during the summer months occurs as brief thunderstorms.

Daily temperatures can differ by as much as 22°C (40°F), which can cause "frost heaving" of planted seedlings. Freezing and thawing is a very significant weathering process near the soil surface.

Daily high temperatures during the summer range from about 19°C (66°F) to 33°C (100°F) and lows during the winter range from about -7°C (19°F) to 10°C (50°F) (NOAA, 1982).

Geology and Soils

The major rock units of the Siskiyou Mountains are the Dothan, Umpqua and Solice formations, the Applegate group, Ultramafic rocks and Intrusive rocks. The White Creek site is underlain by the Applegate group, which was laid down during the upper Triassic (deMoulin et al., 1975). The metavolcanic and metasedimentary rocks of this group are described by Wells and Peck, 1961, as pale-green to greenish-gray altered flows and some tuff breccia, flow breccia, stratified tuff, and related intrusive rocks mostly of andesitic or basaltic composition. Flows are commonly fine-to coarse-grained, porphyritic, vescular, or amygdaloidal.

The Soil Inventory of the Medford District conducted by the BLM (1973) identifies three unnamed soil series in the area of the White Creek site location. The soil series are numbered 370-382-371, and a description of each is given in Appendix I.

The unit number (370-382-371), consists of moderately deep, very gravelly loamy and clayey soils. The loamy 370 soils make up about 40 percent of the unit and are randomly mixed with the clayey 382 soils that make up about 35 percent of the unit. The loamy 371 soils occupy the steeper slopes and higher positions on the landscape and make up about 25 percent of the unit (deMoulin et al., 1975). Table 1 gives some interpretive ratings for selected soil properties and qualities of each of the three soil series numbers, which comprise the unit number 370-382-371.

TABLE 1.

Some characteristics of the soil series 370-382-371 (deMoulin, et al. 1975).

	Soil Series Symbol		
	370	**382**	**371**
Depth (inches)	40+	40+	20-40
Permeability	Moderate	Moderately Slow	Moderate
Drainage	Well Drained	Well Drained	Well Drained
Available Water Capacity (inches)	3-6	3-6	3-6
Water Supplying Capacity (inches)	7-14	13-18	5-10
Compaction Hazard	Moderate	Moderate-Severe	Slight
Frost Susceptibility	Severe	Moderate	Moderate
Erosion Susceptibility	Severe	Severe	Severe
Regeneration Hazard	Slight	Moderate	Severe

Vegetation

The White Creek site falls into the Mixed-Evergreen Zone described by Franklin and Dyrness (1973). Differences in tree species can vary considerably within the same area. Site factors such as elevation, aspect, and soils are major contributors to species composition. However, the most important tree species in the Mixed-Evergreen Zone are Douglas-fir (Pseudotsuga menziesii) and tanoak (Lithocarpus densiflorus); these are also judged to be the major climax tree species. Other hardwoods present include bigleaf maple (Acer macrophyllum) canyon live oak (Quercus chrysolepis), Pacific madrone (Arbutus menziesii), gold chinkapin (Castanopsis chrysophylla), and California laurel (Umbellularia californica). Two other conifers present in small numbers are incense-cedar (Libocedrus decurrens) and Port-Orford cedar (Chamaecyporis lawsoniana).

The shrub layer averages about thirty percent cover and is typically composed of Oregon grape (Berberis nervosa), Pacific poison oak (Rhus diversiloba), baldhip rose (Rosa gymnocarpa), trailing blackberry (Rubus ursinus), and California laurel (Umbellubarum californica).

Before logging and broadcast burning, the sparse overstory on this site allowed enough light for a large number of Douglas-fir (Pseudotsuga menziesii) and various hardwood seedlings to be present in the understory.

The herbaceous layer was not well developed, except in areas where there was little overstory shading. Percent shade from herbaceious plants ranged from 6 to 10 percent and was typically composed of swordfern (Polystrichurn muniturn), whipple vine (Whipplea modesta), braken fern (Pteridium aquilinum), Hooker's fairybells (Disporium hookeri), western fescue (Festuca occidentalis), and California honeysuckle (Lonicera hispidula).

CHAPTER IV

MATERIALS AND METHODS

Field Methods

Selection of Sampling Periods

All field sampling occured from May to November of 198~~3~~2. A field sample period was conducted before the fire, and followed by five sample periods after the fire. The timetable of field sampling was as follows:

Activity	Date	Days Since Burn
Pre-Burn Measurement	May 18	-20
Broadcast Burn	June 7	0
Post-Burn Measurements	June 16	9
	July 21	44
	August 26	80
	October 7	122
	November 10	156

Initially, measurements were conducted once per month, but inclement weather and personal time restrictions resulted in obtaining five sampling periods, rather than six during the six month span of sampling.

An effort was made to conduct sampling after the soil had a few days to drain if a precipitation event had occurred before or at the time of the intended date of sampling.

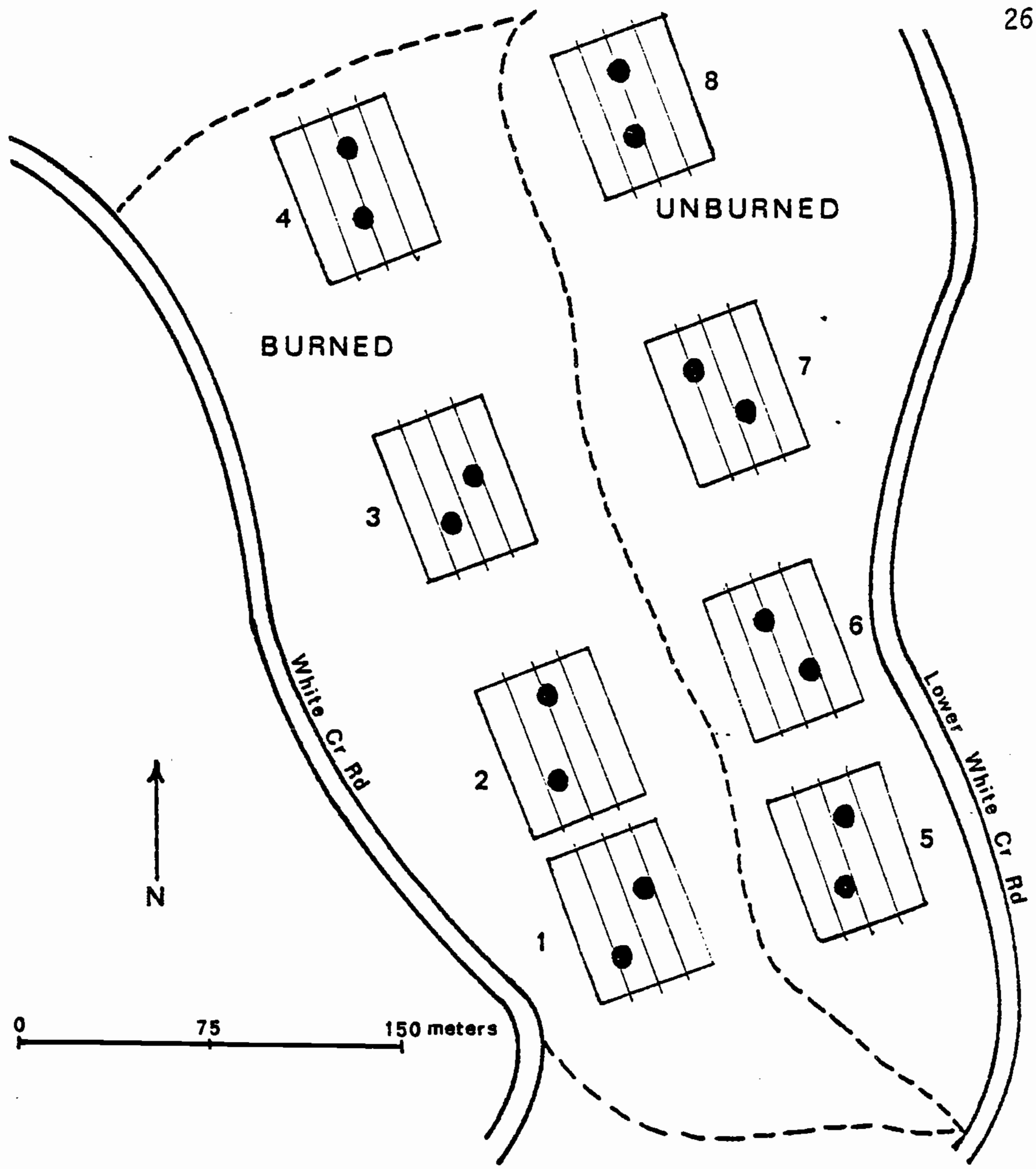
The last sampling period in November proved adequate for this study. Further sampling from that date may have encountered snowfall accumulations, frozen soil, or heavy rainfall.

Sampling Procedure

The site was divided into a burned section and an unburned or control section. The sections were separated by a fireline with the burned area upslope from the unburned (Figure 3). Four, 0.25 ha plots were established on either side of the fire line, dividing the unburned from the burned portion of the unit. Burned and unburned plot pairs were located to enhance soil and site uniformity within each plot pair.

Within each plot two infiltration points were randomly located, to measure infiltration capacity. However, it was necessary to relocate an infiltration point if it fell on soil significantly compacted by human activity during logging, broadcast burning, or previous field sampling. Once the first infiltration points were established, an effort was made to locate future infiltration measurements on undisturbed soil near the original.

At each orginal infiltration point an empty coffee can was placed upright and flush with the soil surface. The can was filled with water prior to the burn and the amount of water evaporated by the heat of the burn was recorded.



- Infiltration and soil sample point
- Plot location
- Fire line
- Surface wettability transect
Fire intensity transect

Figure 3. Plot layout at the White Creek site.

Burn Intensity

At each infiltration point, date, time of measurement, and percent slope was recorded. A visual estimation of fire intensity was made, using guidelines set by Boyer and Dell (1980), described in the Literature Review section on page 5.

During each monthly sample period notes were taken describing physical changes in the site's appearance, which mostly related to the occurrence of residual and invading vegetation.

Infiltration Measurements

Infiltration capacities were determined with a modified version of the infiltrometer developed by the School of Forestry, Oregon State University (Froehlich and Hess, 1976). As a rainfall simulator, the O.S.U. infiltrometer applies water uniformly to an area of 3122.6 cm^2 at a controlled rate (Figure 4).

Chow and Harbaugh (1965) originally used this type of instrument for laboratory tests, while Meeuwig (1971) altered it for field work, before further refinements at Oregon State University. The O.S.U. infiltrometer needed to be specially designed for use on the steep slopes encountered in this study (Figure 5). Initial alterations were conceived by Dr. Henry Froehlich and Dave McNabb when it was discovered that the use of legs for the infiltrometer would be impractical on the 70-80% slope. A tripod was fashioned by Dave

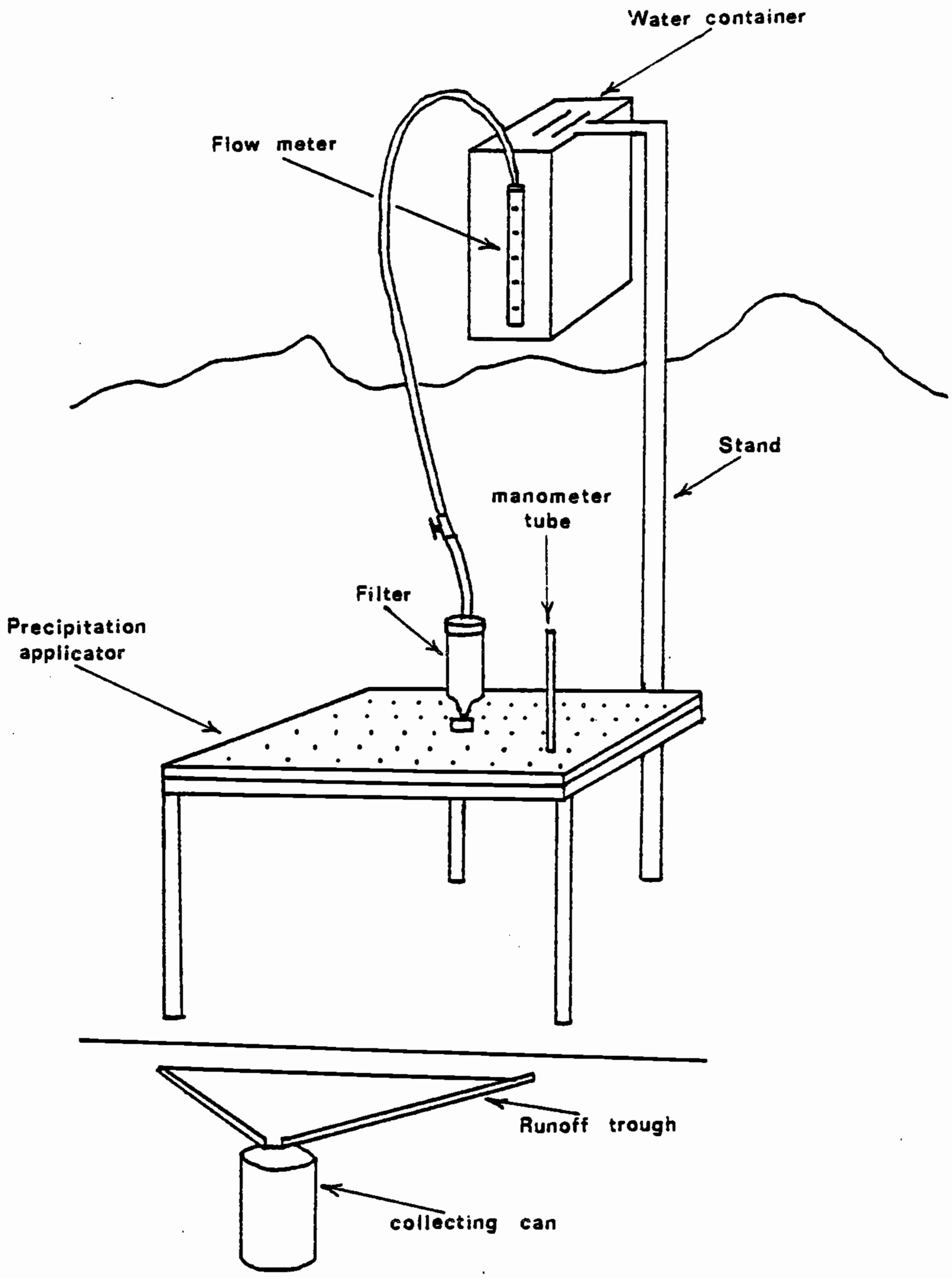


Figure 4. The O.S.U. infiltrometer before modification.

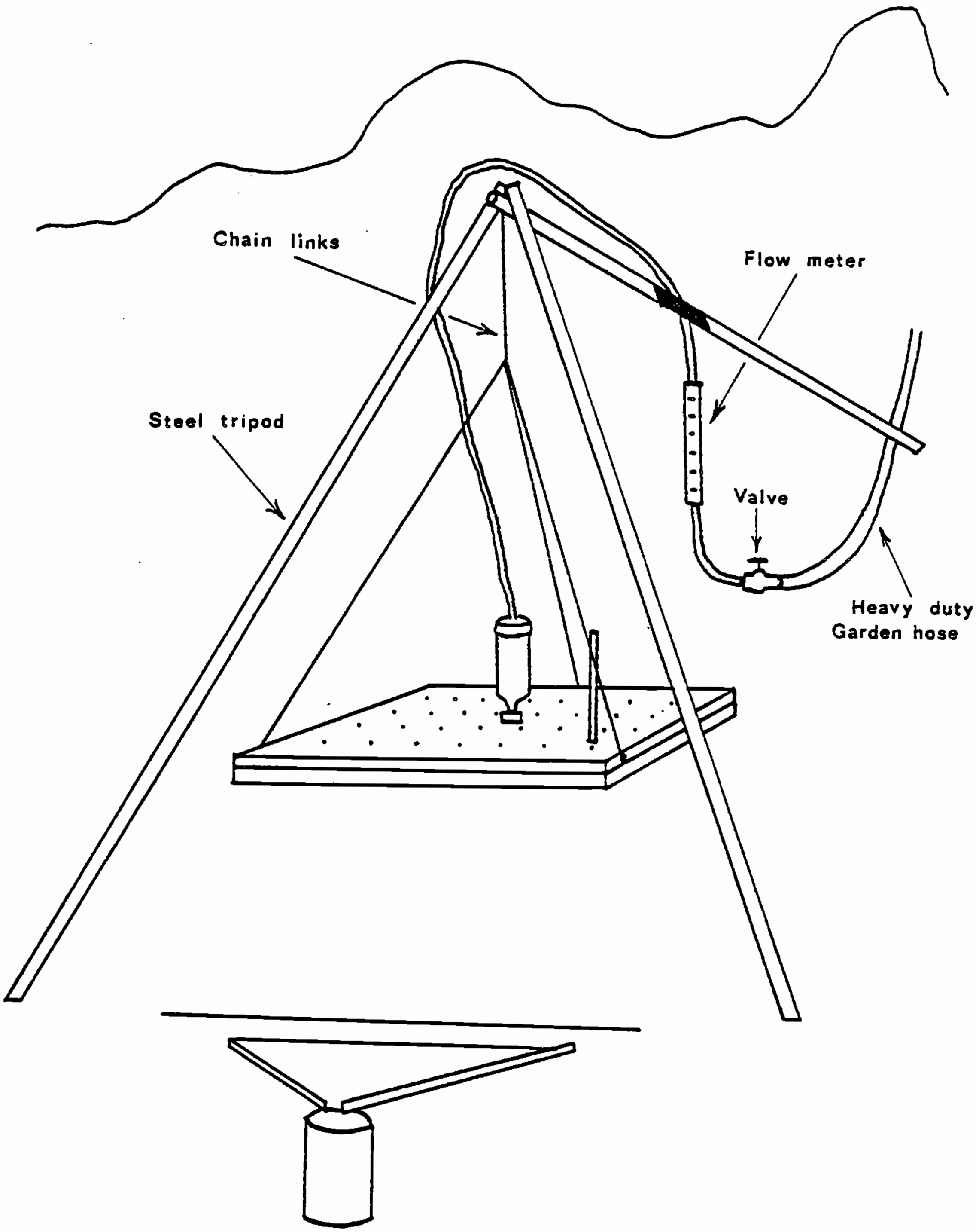


Figure 5. The O.S.U. infiltrometer after modification for steep slopes.

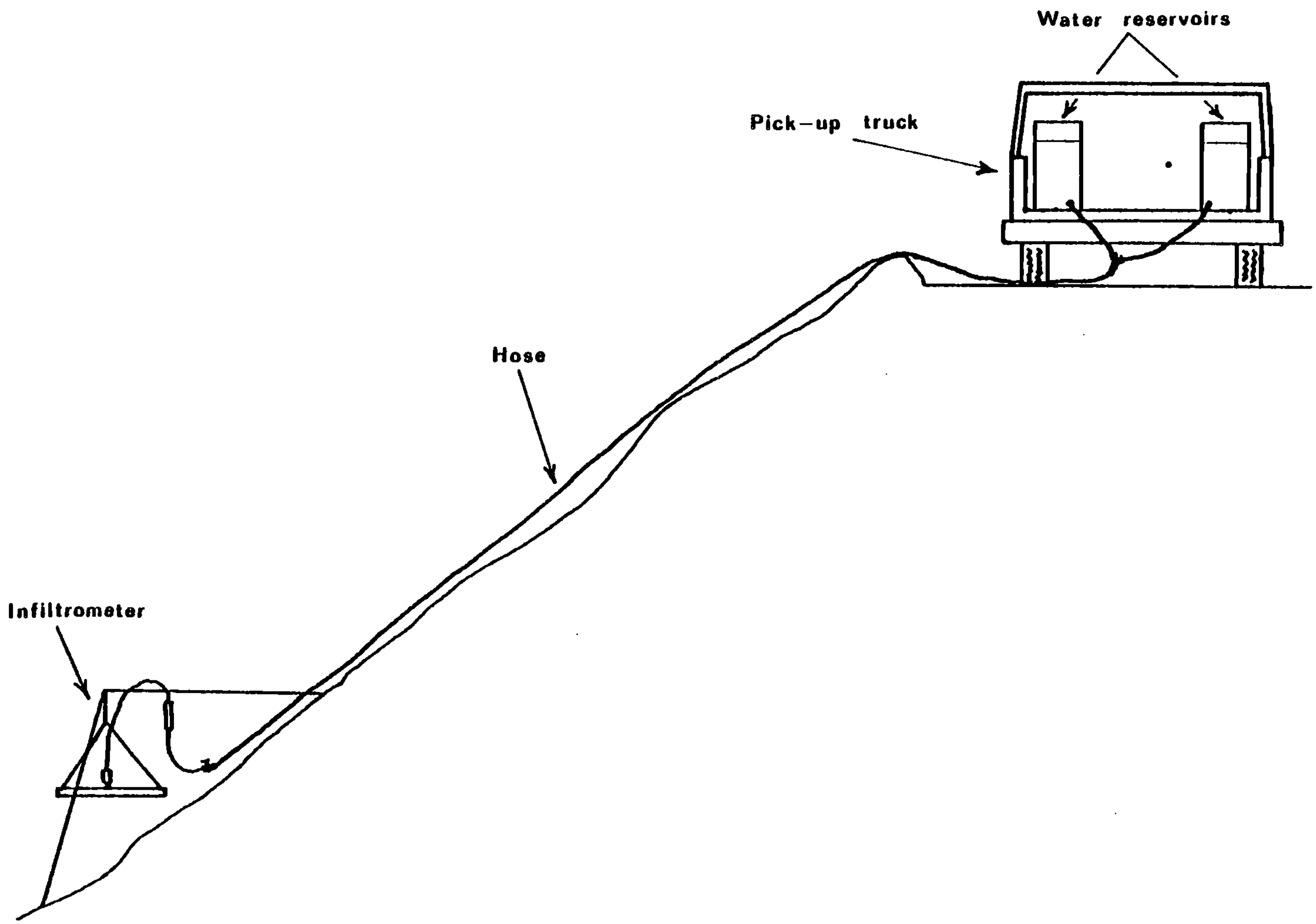


Figure 6. Infiltration measurement system used on steep slope.

McNabb, which proved to be much more efficient during set-up and take-down. Further alterations were devised by Frank Gaweda. Previously, a 18.9 L (5 gal) water tank was suspended on a stand 1.5m above the ground as a constant pressure head reservoir. In its place, two 113.6 L (30 gal) reservoirs were used and placed in a pick-up truck on the road above the site (Figure 6). The reservoirs were connected to the infiltrometer via 1.9 m (0.75 inch) garden hose with a valve inserted between the garden hose and a rubber tube, containing a calibrated flow gauge. The tube was then connected to the infiltrometer. Elevation pressure head was utilized to obtain water flow. The flow gauge indicates the precipitation rate, and may be adjusted by opening or closing the valve. Runoff from the infiltration point is diverted to a collection can by a steel trough which is installed directly downslope of the infiltrometer. Infiltration capacities are determined from measured rates of application and volume of runoff.

The infiltrometer was leveled after being placed on the randomly located infiltration point. Once the position of the infiltrometer was established, live vegetation and litter were removed with minimal disturbance to the soil surface. This was done to insure that if runoff occurred it was because the maximum infiltration capacity of the mineral soil surface had been exceeded. Two 20 minute infiltration runs were conducted with a 15 minute pause between, which allowed water to drain into the profile. The first was a pre-wet run, which assured relatively uniform conditons between infiltration points, in addition to, approaching a constant infiltration rate prior to the second run.

The total runoff collected in collecting cans during each run was measured with a 500 ml graduated cylinder and recorded separately for each 20 minute run. The total volume of runoff was converted from ml/hr to cm/hr.

An intensity of 11.4 cm/hr (4.5 in/hr) was used for both runs. Although 11.4 cm/hr greatly exceeds the usual intensities for this area, it was used so that infiltration capacities could be determined for porous forest soils in a short time period with an improved degree of accuracy (Meeuwig, 1971). This proved to be a good assumption since undisturbed soil had infiltration capacities greater than 11.4 cm/hr. A higher intensity was viewed to be impractical due to the limited amount of water available and the travel distance necessary to replenish the water supply. By using equations developed by Miller et al. (1973), the 1-hr values of maximum precipitation intensity for a 2 year and a 100 year event at this particular location, are 1.4 cm/hr (0.54 in/hr) and 2.9 cm/hr (1.15 in/hr) respectively.

Soil Wettability

Soil wettability was determined in the field at the mineral soil surface using the Water Drop Penetration Time Test (WDPT) developed by DeBano (1966). A distilled water droplet was placed on the mineral soil surface and the time required for the droplet to penetrate into the soil recorded. A sample point was considered nonwettable if the water drop remained on the soil surface longer than 10 seconds (Adams et al. 1970).

A systematic sampling procedure was utilized, which consisted of three transects laid out along the slope, across each burn and control plot (Figure 3). Sixteen or seventeen sampling points were evenly spaced along a transect to give each plot approximately 50 points.

The number of nonwettable points was recorded and the percent of the mineral soil surface in this condition could be calculated.

Collection of Soil Samples

A soil bulk sample was taken near each infiltration sample point. A pick was used to expose a soil profile and samples were taken from the following depths; 0-5 cm, 5-15 cm, 15-30 cm. Due to the high percentage of rocks and gravel in the soil, it was impossible to obtain an undisturbed sample by inserting a sampling core into the soil down to the desired depth.

The soil samples were taken after all other tasks had been completed for the sampling period. Samples were collected in air-tight soil cans, marked, and immediately transported back to the O.S.U. soil laboratory for weighing.

Laboratory Analysis

Soil Moisture

After the soil samples were weighed and tested for wettability, they were dried in a conventional 105° C oven for 48 hours prior to re-weighing. Gravimetric soil moisture was calculated for each soil sample.

Soil Wettability

Water drop penetration time (Debano, 1966) was used to determine soil wettability of both wet and oven-dry soil samples. A drop of distilled water was placed on the soil sample and the time of penetration recorded in seconds. This was repeated five times for each sample and an average water drop penetration time was obtained. Air-dry soil is normally used when determining wettability, but the small size of the individual bulk soil samples made it impossible to divide them for determining soil moisture and wettability separately. As a result, the samples were oven-dried and soil moisture percent was determined prior to conducting the wettability experiments.

Soil wettability was also tested by measurement of apparent liquid-solid contact angle (Figure 1) (Letey et al., 1962). While the method may give a more precise index of water repellency, it has come under criticism for several reasons. It does not measure an actual liquid-solid contact angle, but an apparent one that is also a function of pore size. Where pore channels converge and diverge a unique relation between relative sorptivity and contact angle does not exist (Philip, 1971; Bond and Hammond, 1970). A second disadvantage is that this method is not a true equilibrium measurement as the derivation of the equation assumes. The height of capillary rise for a clay column versus a sand column will be ultimately more, but occur over a greater length of time. The usual time of the test, 24 hours, may not be long enough for all the soil samples to reach equilibrium. However, this technique does give a useful measure of the wetting difficulties in soil. Appendix II gives a derivation of the capillary rise equation used

$$\cos \theta_w = \frac{h_w \gamma_e \rho_w}{h_e \gamma_w \rho_e}$$

θ_w = soil contact angle

The procedure was to sieve the soil sample through a #10 standard sieve to remove particles greater than 2mm in diameter. The sample was weighed out into two identical masses of soil and packed by gentle tapping to the same height in 1cm glass tubes. A filter paper covering was previously secured at the bottom of each tube to prevent soil from escaping. One soil column was placed in ethanol, and the other was placed in water (Figure 7). The height of capillary rise was measured for each given solution after 24 hours. Temperature was recorded to adjust the surface tensions and densities of the ethanol and water.

Soil Texture

Soil samples collected after the burn were used to determine the standard USDA textural classes for these soils. The procedure utilizing hydrometer analysis in "Grain-Size Analysis of Forest Soils" (Froehlich, 1978) was performed on the fraction smaller than two mm in diameter. Appendix III outlines the procedure and shows the necessary calculations.

All the soil samples normally taken for determining moisture in the four burn plots were analyzed for texture. There was not a sufficient quantity of soil taken from the unburned plots to do an analysis of each plot. Therefore, these soil samples were combined to give the textural classes at the three different depths. Since the unburned section was not disturbed from burning at varying intensities, it was assumed that the soil texture would be similar throughout all the plots, thus allowing the soil samples to be pooled.

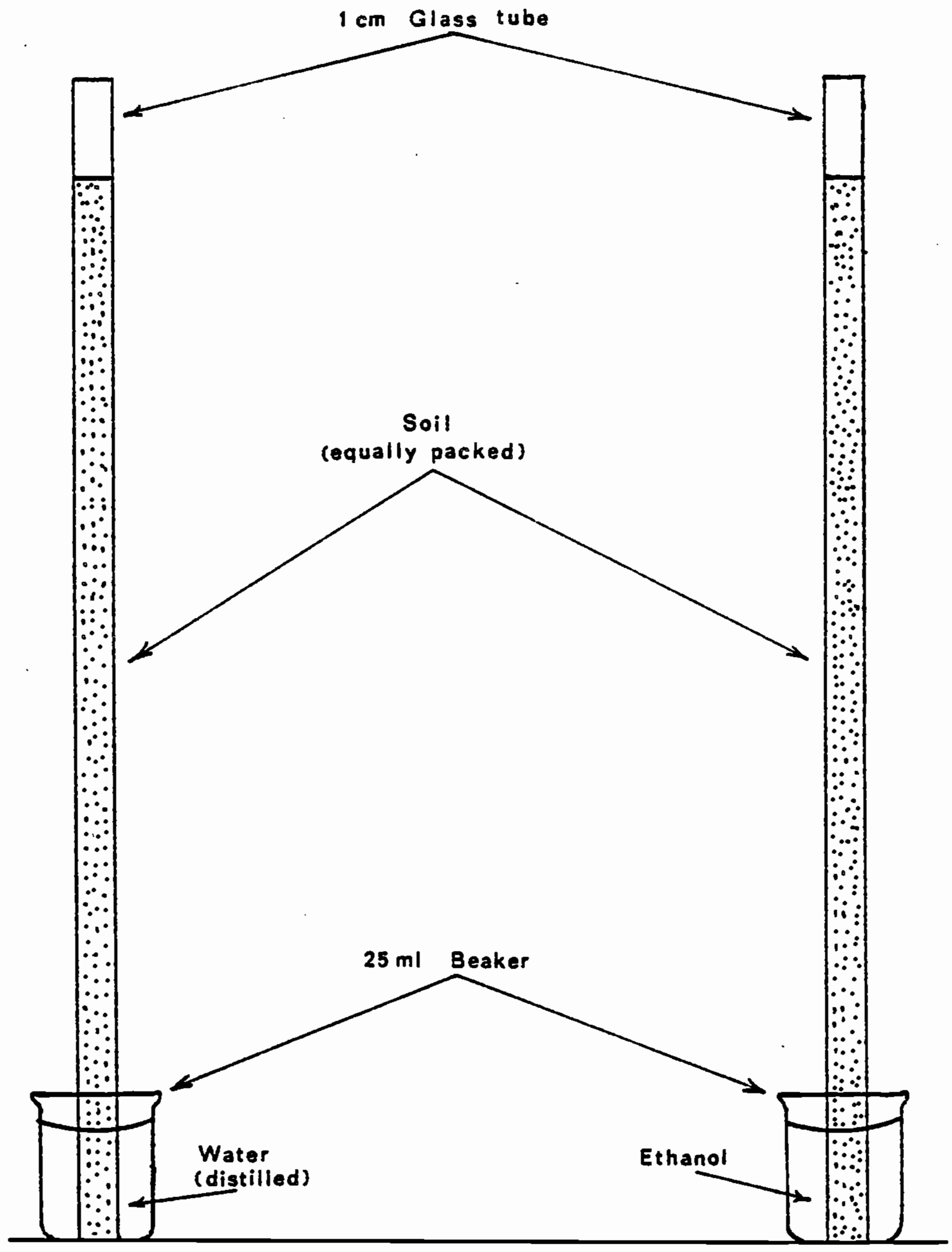


Figure 7. Apparatus used to measure the capillary rise of a soil sample for two liquid mediums.

CHAPTER V

SUPPLEMENTAL RESEARCH

Purpose

Since the White Creek site was moderately to lightly burned, another broadcast burned site with a heavier fuel loading was selected to be measured for infiltration rate, soil moisture, contact angle, and percent repellency of the soil surface. These parameters were measured for one sample period in August, 66 days after a broadcast burn, to verify measurements taken at the White Creek site, and to see if a higher intensity burn would have a significantly greater effect on measured soil variables. The major criteria for selection of an additional site was that it contained similar soils, topography, and climate as the White Creek site.

Site Description

The Shan Basin Timber Sale Unit 1 was selected and is located in the Galice Ranger District of the Siskiyou National Forest in the NE 1/4 of section 4, Township 36 South, Row 7 West, Willamette Meridian.

The total area of the Shan Basin Site is about 23 ha with a north aspect. The mean elevation is approximately 670.6 meters (2200 feet) above sea level and slope percent ranges from 40 to 85 percent, with an average of about 65 percent.

The average annual precipitation at the Shan Basin site is about 102 cm (40 inches) with a value for the growing season (May through September) of 10 to 13 cm (4 to 5 inches) (Froehlich et al., 1982). Other climatic factors such as daily temperature and snowfall accumulations are similar to the White Creek site.

Although the Shan Basin site lies on USDA Forest Service land, the BLM's Soil Inventory of the Medford District was used to identify the major soils, due to the close proximity of BLM land north and east of the site (1584 and 1056 feet respectively).

The unit number (718-701) identified for the Shan Basin site consists of 80 percent of moderately deep, very gravelly, loamy (718) Beekman soils and 20 percent of shallow 701 soils. The 701 soils occupy the steeper slopes and ridges. Inclusions of moderately deep, fine-loamy Colestine soils are mixed with the (718) Beekman soils, and rock outcrops are mixed with the 701 soils. Adjacent to areas of higher precipitation, these soils merge with the loamy, very gravelly soils of the 370-382-371 series that are typical of the White Creek site (deMoulin et al., 1975). Separate descriptions of the (718) Beekman soils and the 701 soils are given in Appendix I.

The Shan Basin site lies within the Mixed-Evergreen Zone previously described for the White Creek site. The major difference noted was the greater slash loading in the Shan Basin site, due to a denser overstory of Douglas-fir (*Pseudotsuga menziesii*) prior to logging.

Sampling Methods

The same sampling procedure outlined for the burned section of the White Creek site during a single sample period was used. The exception being that the eight infiltration points were not established within four plots. Instead, a systematic sample of eight infiltration points, located on a line transect, bisected the site in half. At each infiltration point, infiltration rates, slope percent, soil samples, etc., were obtained as at the White Creek site. The laboratory methods used to analyze the soil samples for the White Creek site were also used for the Shan Basin site.

Since four specific plots were not established at the Shan Basin site, the transects used for the Water Drop Penetration test to determine the percent of the surface soil which was water repellent, were located throughout the site in an effort to obtain a uniform measurement.

An unburned, clearcut section was not established at the Shan Basin site, but four infiltration measurements were taken in adjacent forestland and used as a control measurement.

CHAPTER VI

RESULTS AND DISCUSSION

Burn Intensity

Burn intensity was best determined by visual observations along the water repellency transects. Each point was classified as light, moderate, or severe.

The method of measuring the amount of water evaporated from the water cans to determine heat capacity, was not useful. Field technicians were unaware of the can locations and accidently dislodged soil on the steep slopes, which was often deposited in the cans. Data obtained from the coffee cans was therefore determined to be unreliable.

All the burn intensity observations at the White Creek site were accumulated to give a classification for each plot. Since the Shan Creek site did not contain separate plots, intensity data was accumulated for the entire site area only. The result of these observations are presented in Table 2.

Precipitation records for Cave Junction indicate that 1.5 cm (0.60 inches), 0.1 cm (0.04 inches) and 0 cm of precipitation were recorded three consecutive days prior to the burn at White Creek. The antecedent moisture in the soil combined with increased moisture percentage in the fuel probably accounted for a moderate-to-light intensity burn. In contrast, precipitation records for Grants Pass

Table 2.

Burn intensity observations.

Plot No.	Percent Light	Moderate	Severe	Description
1	50	45	5	Light to Moderate
2	25	65	10	Moderate
3	70	30	0	Light to Moderate
4	40	60	0	Moderate to Light
Average (White Creek)	46	50	4	Moderate to Light
Average (Shan Creek)	21	70	9	Moderate

indicate that no precipitation occurred for 33 days before the burn at Shan Creek. The result was a moderate intensity burn.

Fuel loading was another factor in explaining the differences in intensity for the two sites. The total down and dead fuel weight before the Shan Creek burn was 78,458 kg/ha (35 tons/acre), with a slash depth from 31 cm (12 inches) to 102 cm (40 inches). Although figures are not yet available for the White Creek site at the time of this report, an estimate of slash depth ranged from 3 cm (1 inch) to 76 cm (30 inches).

The heaviest accumulation of slash in the White Creek site, occurred in plots one and four. These two plots also had a large percentage of moderately burned soil. The small percent of severely burned soil in plot number one was due to a couple of 61 cm (24 inch) downed and dead logs, which conducted high temperatures of longer duration to the adjacent soil. A study by Tarrant (1956) suggested that severely burned soil is typically spotty and usually occurs under large logs or slash piles. The percent of severely burned soils was greatest in plot two. Ironically, this plot did not have a heavy slash loading before burning, but there was a thicker layer of litter and duff. Although rainfall occurred prior to burning, the month of May was very dry in southwest Oregon and the higher percent of soil organic matter in plot two may have been dry enough for significantly greater consumption during the burn. This would lead to high heat conduction at the 0-5 cm depth of soil.

Soil Texture

The USDA textural classes determined by hydrometer analysis on soils at White Creek are given in Table 3.

Soil Moisture Levels

Burned vs. Unburned

Due to the dry summers, soil moisture levels are rapidly depleted by vegetation on forested sites in southwest Oregon. Since moisture is the most limiting variable when trying to establish regeneration, an investigation of burning effects on soil moisture can be valuable.

At all three soil depths the burned and unburned sections both experienced large reductions in soil moisture during the months of July and August. The pattern of precipitation indicates a period of zero rainfall accumulation between July 1 and August 27. The extent of soil moisture depletion at all three depths contrasted sharply between the burned and unburned sections during July and August. Differences were found to be significant at the 5 percent level. In addition, soil moisture measured at 5-15 and 15-30 cm divulged significant differences between the burned and unburned section for the month of June. Prior to the burn, the means of soil moisture percent in the burned and unburned sections were nearly equal at all three depths (Figures 8 and 9).

TABLE 3

The particle size distribution of bulk soil samples, expressed as a percent of coarse-fragment content (C-f), sand, silt, and clay, and determined by hydrometer analysis.

	Burned					Unburned
	Plot Number					
Depth	1	2	3	4	Avg	Avg
0- 5 cm						
C-f	77	77	68	76	75	70
Sand	51	52	48	51	51	48
Silt	27	27	27	27	27	27
Clay	22	21	25	22	22	25
5-15 cm						
C-f	69	73	70	75	72	71
Sand	42	42	45	31	40	39
Silt	31	38	29	42	37	36
Clay	27	20	16	27	23	25
15-30 cm						
C-f	73	75	73	70	73	74
Sand	41	47	41	39	42	38
Silt	31	24	31	32	30	35
Clay	28	29	28	29	28	27

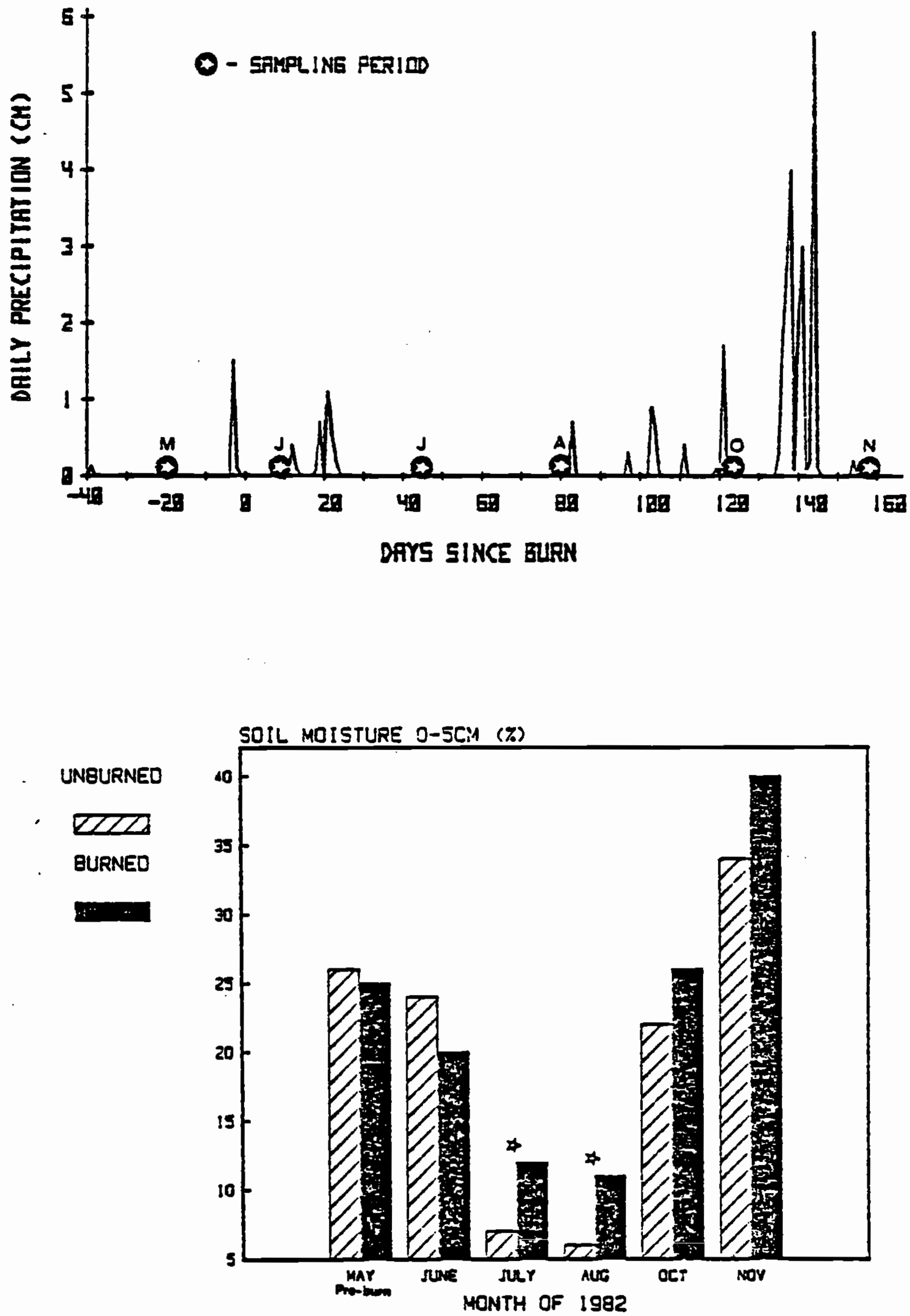
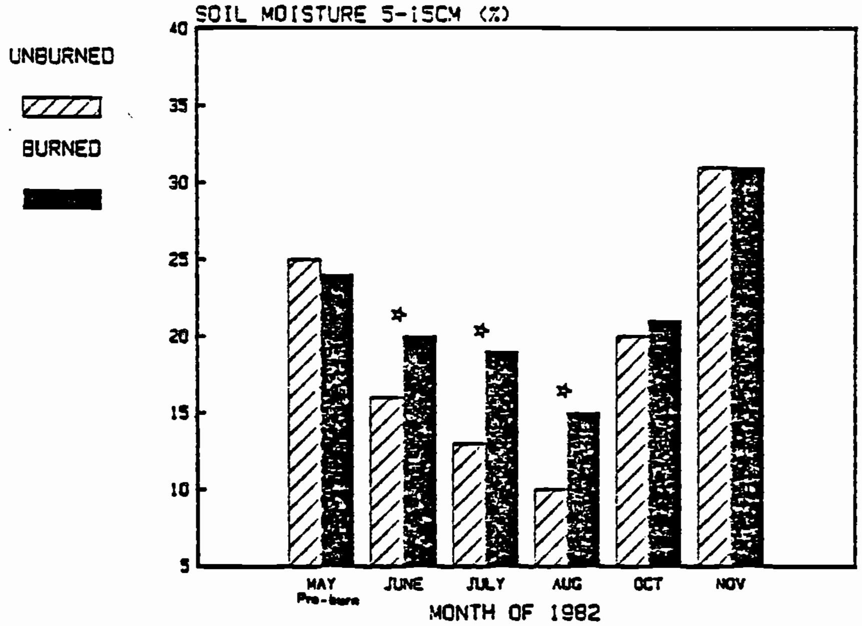


Figure 8. The daily precipitation pattern recorded at Cave Junction and comparison of burned and unburned soil moisture for the 0-5 cm soil depth at White Creek.
☆ - indicates a significant difference at $\alpha = 0.05$



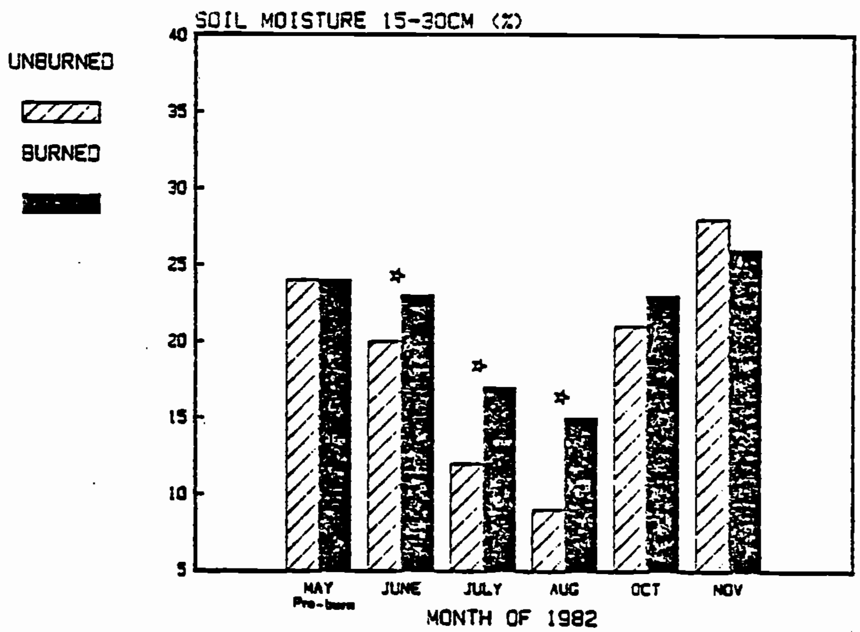


Figure 9. Comparison of burned and unburned soil moisture for the 5-15 cm and 15-30 cm soil depths at White Creek. ☆ - indicates significant difference at $\alpha = 0.05$.

After the burn, soil moisture was consistently lower in the unburned section at 5-15 and 15-30 cm. This condition lasted until the last sample period in November, when soil moisture in the unburned section was slightly higher. Residual vegetation after forest harvesting in the unburned section was undoubtedly the major reason for greater moisture depletion. Stump sprouts and invading vegetation did not become well established in the burned section until the October sample period (Figure 10). A total of 6.3 cm (2.5 inches) of precipitation accumulated between the August and October sample periods. It was too dry prior to this time for revegetation of the burned section. Increased precipitation and lower evapotranspirational demands, combined with vegetation becoming re-established in the burned section, led to differences between burned and unburned soil moisture not being significant during the October and November sample periods. Bethlahmy (1962) found that, in the year following timber harvest, but before the cutover has been invaded by competing vegetation, minimum soil moisture contents have been considerably lower on the timbered areas than on the adjoining cutover and burned area. However, Hallin (1967) concluded that the vegetation which has invaded the cutover eventually is as effective as the old-growth stand in depleting soil moisture at 15 cm (6 inch) and 45 cm (18 inch) depths and nearly so at the 90 cm (36 inch) depth. Although the vegetation in the unburned section of the White Creek site does not represent an old growth condition, the vigorous

Figure 10. Photographic comparison of White Creek 9 days (June 16) and 122 days (October 7) after a broadcast burn.

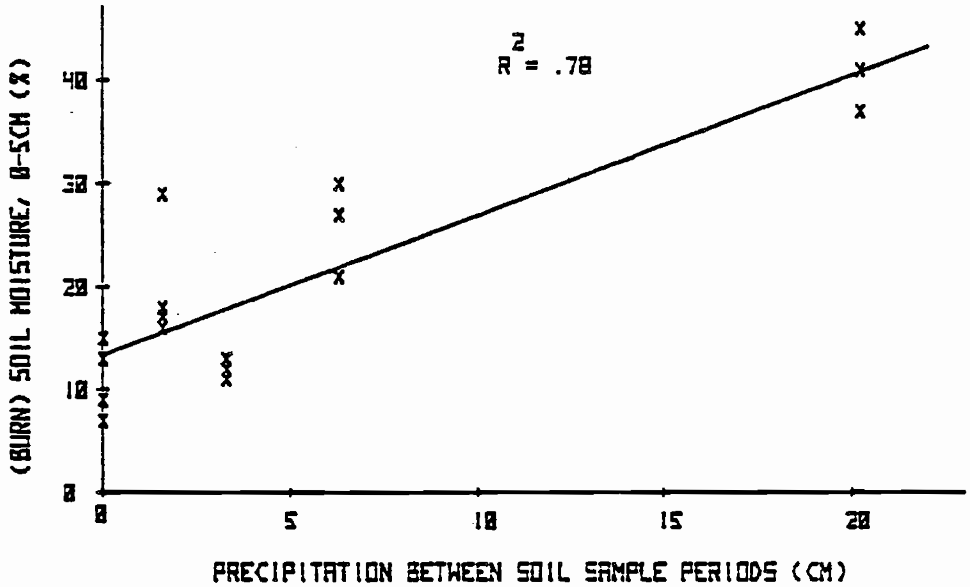
growth after the removal of the overstory probably accounts for the differences in burned vs. unburned conditions found in this study.

Some authors have found reductions in soil moisture properties such as water-holding capacity (Agee 1973), and moisture equivalent (Austin and Baisinger 1955) immediately following burning, while Blaisdell (1953) found reductions in soil moisture itself. These reductions are often related to consumption of soil organic matter where burning was severe. This may account for the 0-5 cm soil moisture in the burned section of White Creek actually being lower than the unburned nine days following the burn. Since no precipitation occurred during these nine days, it was inferred that the burn was hot enough to vaporize moisture and consume some organic matter at the 0-5 cm depth. This was not observed at deeper soil depths. After 3.3 cm (1.3 inches) of precipitation accumulated prior to the next sample period in July, the situation was reversed and soil moisture at the 0-5 cm depth was higher in the burned section. This trend continued through November, but was only statistically significant during July and August. If soil moisture had remained consistantly lower in the burned section, it would have been deduced that the soil organic matter was destroyed. However, this was not the case due to a light-to-moderate burn.

Regression Analysis

Of all the measured variables, accumulated precipitation between sample periods was found to be the independent variable which correlated most strongly with soil moisture (Figures 11, 12 and 13) (Table 4). This was especially true at depths of 0-5 cm in the burned section, and 5-15 cm in burned and unburned treatments. Correlation was weak at the 15-30 cm depth in both sections due to a higher moisture content in June even though only 1.6 cm of precipitation had occurred during one storm between the May and June measurements. There was apparently a delay in summer moisture depletion at the 15-30 cm depth when compared to the two shallower depths. Hallin (1967) observed an increasing delay of summer moisture depletion with increasing soil depth.

The 0-5 cm and 5-15 cm soil depths were more susceptible to evaporation and showed a greater dependence on rainfall accumulations. An exception to this was the 0-5 cm depth in the unburned section. The slash and residual vegetative cover protected the surface soil from evaporation in early June, but a lack of precipitation combined with hot summer days limited this effect during July and August.



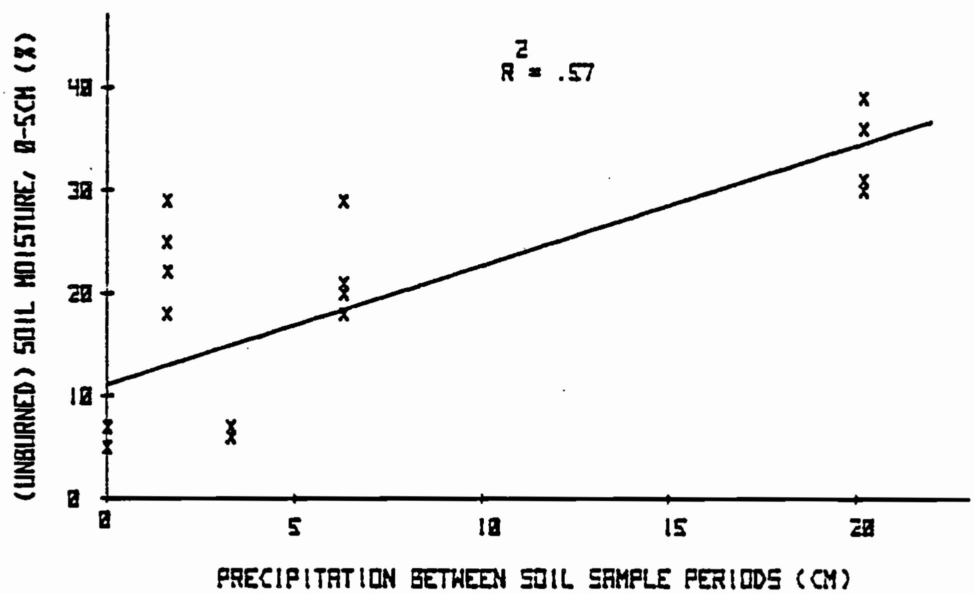
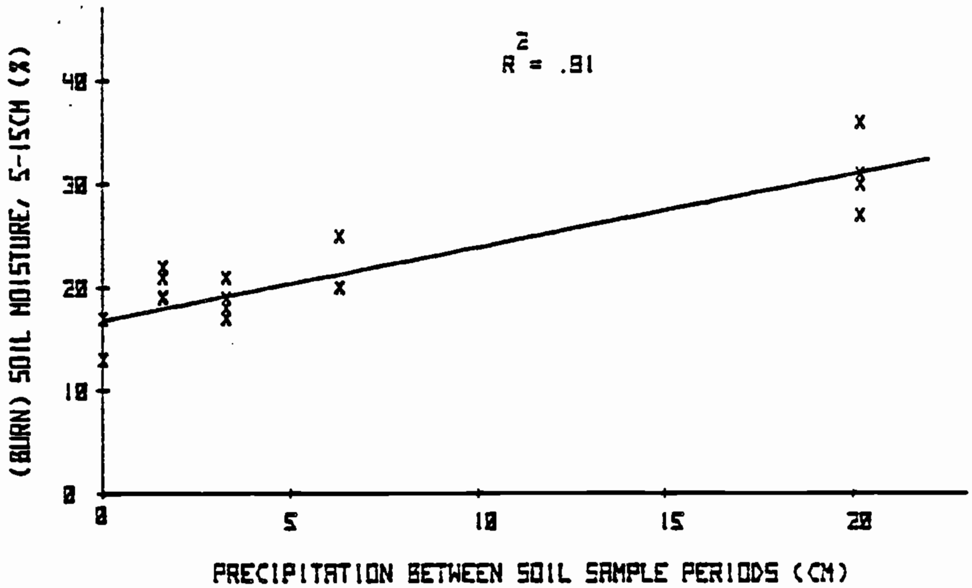


Figure 11. White Creek regression functions for accumulated precipitation between sample periods vs. burned and unburned soil moisture at 0-5 cm depth.



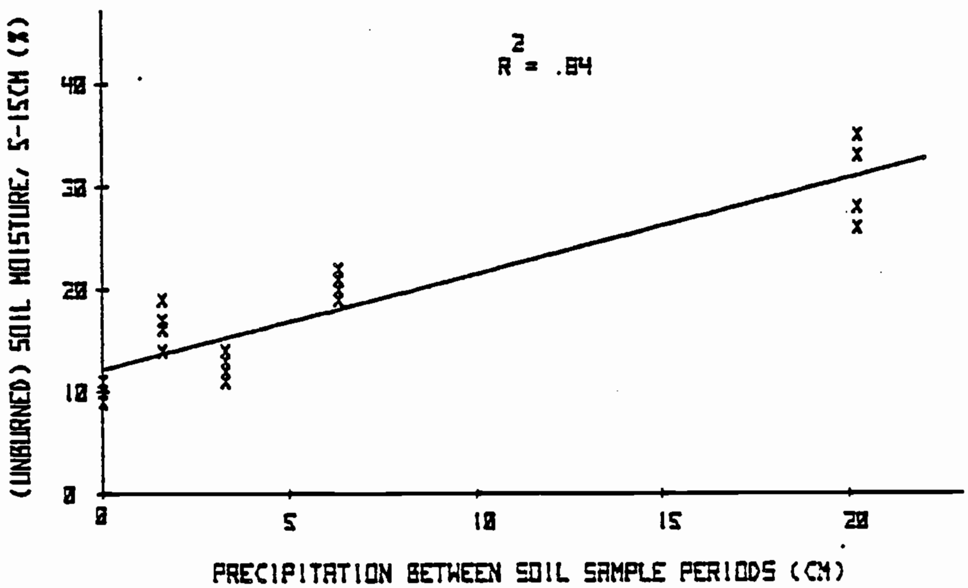


Figure 12. White Creek regression functions for accumulated precipitation between sample periods vs. burned and unburned soil moisture at 5-15 cm depth.

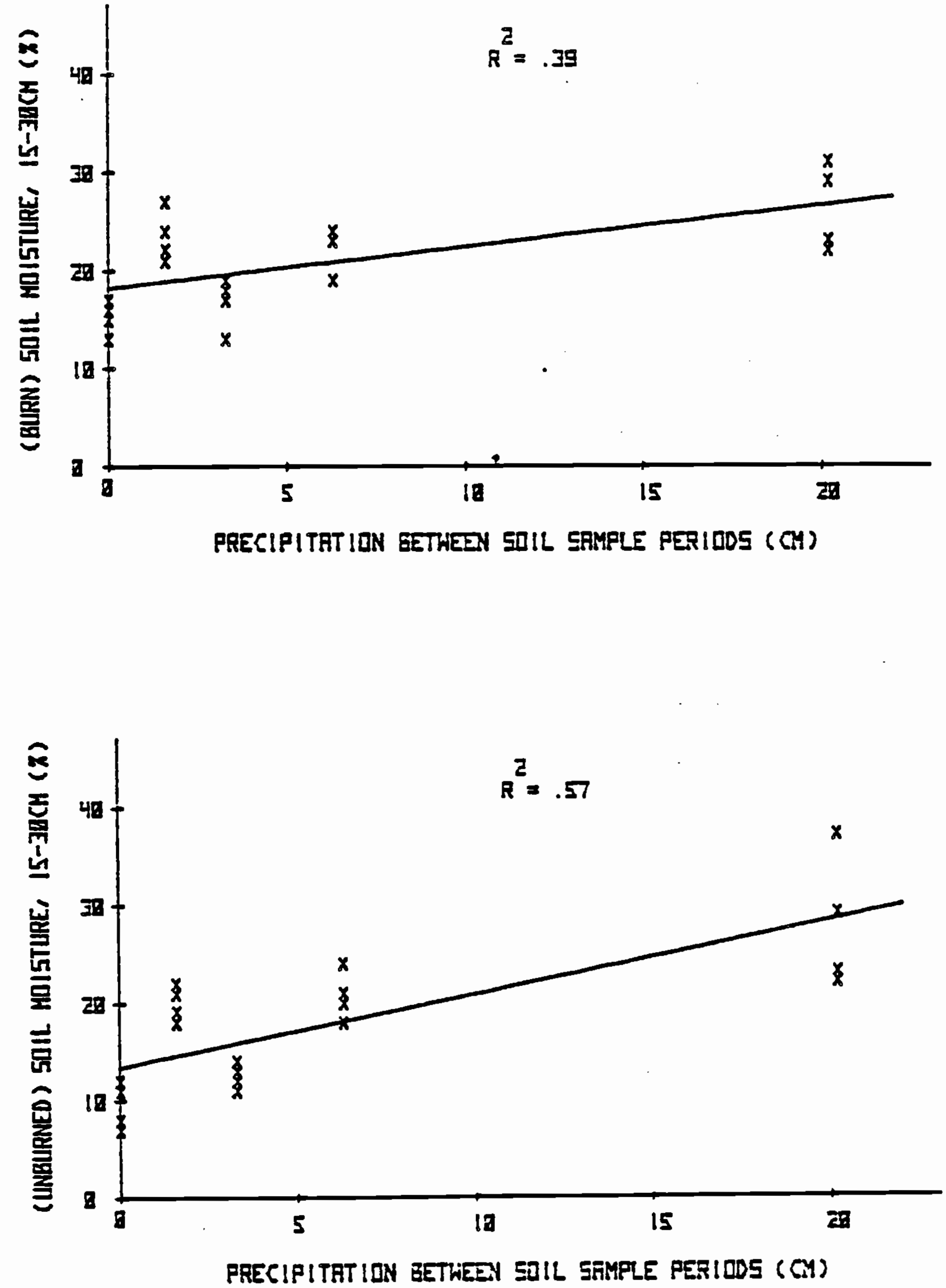


Figure 13. White Creek regression function for accumulated precipitation between sample periods vs. burned and unburned soil moisture at 15-30 cm depth.

TABLE 4

Regression models for the White Creek site using cm of accumulated precipitation between sampling periods as the independent variable (x) and soil moisture percent as the dependent variable (y).

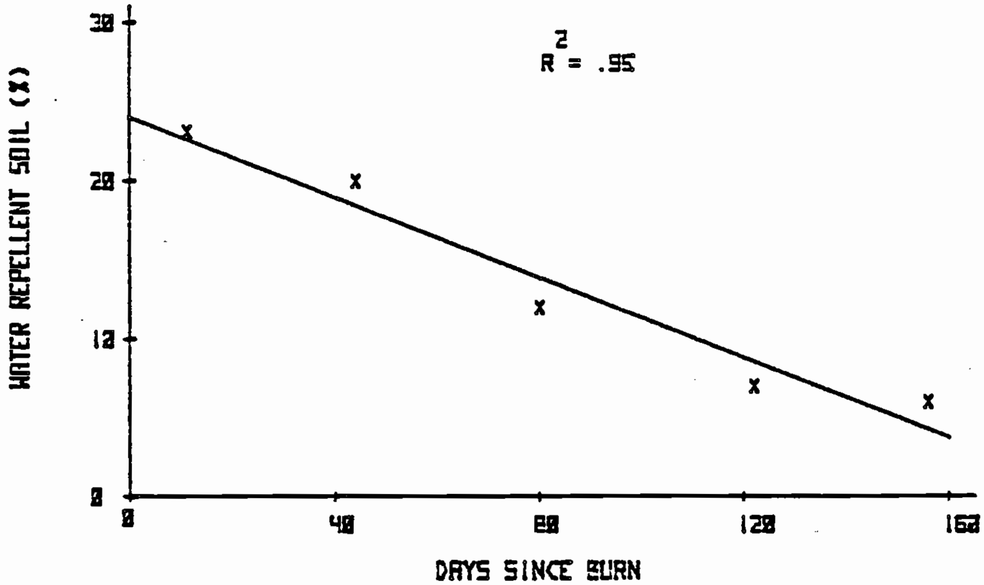
Soil Depth (cm)	Treatment	Model	F Statistic	r^2	n	Figure No.
0 - 5	Burn	$y = 13.4 + 1.36x$	64.3	0.78	20	11
	Unburned	$y = 11.1 + 1.16x$	23.8	0.57	20	11
5 - 15	Burn	$y = 16.8 + 0.71x$	75.0	0.81	20	12
	Unburned	$y = 12.2 + 0.93x$	91.3	0.84	20	12
15 - 30	Burn	$y = 18.2 + 0.42x$	11.4	0.39	20	13
	Unburned	$y = 13.4 + 0.74x$	23.5	0.57	20	13

Soil Wettability

Water Drop Penetration Test

Field Measurement. - The surface wettability transects used to determine the percent surface soil which was water repellent indicated that, initially following the burn, about 25 percent of the soil in the burned section was water repellent to some degree (Figure 14). This number was linearly reduced over time to a value of 6 percent in November (Table 5). The burned and unburned sections contrasted sharply, as the greatest value measured was only 1 percent in the unburned section. Differences between the burned and unburned sections were significant during June, July, and August, but not in October or November. Although 6 to 7 percent of the exposed mineral soil surface was still repellent in October and November, there was a high degree of variability between plots in the burned area, with plot number 2 containing almost all of the repellent soil that still persisted. The burn intensity was also highest in plot number two (Table 3).

Laboratory Measurements. - The WDPT test, measured in the laboratory on oven dried soil, identified the 0-5 cm depth of soil to be the only depth which consistently showed repellent tendencies. The water drop penetration times measured for all the soil samples were not significantly different before vs. after oven drying. This may be explained by considering that the sample periods of largest WDPT (July and August) also experienced the lowest soil moisture



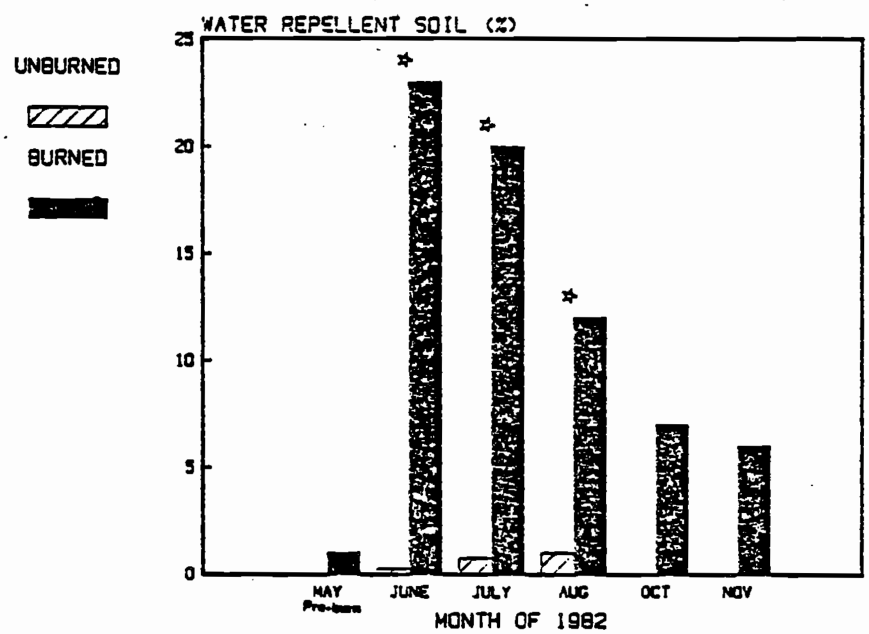


Figure 14. White Creek regression function for percent water repellent soil vs. time, and comparison of burned and unburned water repellency.
☆ - indicates a significant difference at $\alpha = 0.05$

TABLE 5

Regression models significant at $\alpha = 0.05$ for the White Creek site, which pertain to the recovery of measured soil variables to pre-burn levels.

Variables in Regression*	Model	F Statistic	r^2	n	Figure No.
accumulated precipitation since the burn (x) 2nd infiltration run (y)	$y = L_n\,(22{,}864 + 1670x)$	26.8	0.60	20	22
accumulated precipitation since the burn (x) soil contact angle, 0-5cm (y)	$y = \dfrac{1}{L_n[1 + (1.2)(10^{-4})x]}$	28.8	0.62	20	18
accumulated precipitation since the burn (x) water repellent soil (y)	$y = \dfrac{1}{0.04 + (0.03\,\sqrt{x})}$	15.3	0.84	5	18
days since the burn (x) water repellent soil (y)	$y = 24 - 0.13x$	58.0	0.95	5	14
days since the burn (x) accumulated precipitation since the burn (y)	$y = 1.6 + (0.06)(1.04^x)$	346.2	0.99	5	22

*units: accumulated precipitation (cm), infiltration (cm/hr), contact angle (degrees), water repellent soil (percent).

content, therefore the soil samples were almost air-dry prior to oven drying.

Figure 15 displays the WDPT differences between the burned and unburned soil samples. The differences were not statistically significant due to the high variability encountered between soil samples in each treatment.

Contact Angle

The contact angles measured from soil samples taken to the laboratory gave a better indication of the extent of repellency at a particular soil depth. Although the WDPT test is useful in field applications, it is dependent on the wettability and pore geometry of the soil directly beneath the water drop. The capillary rise method is dependent on the same soil properties for an entire soil sample. Variability is much higher using the WDPT test (mean = 19, s = 29) when compared to the capillary rise method (mean = 70, s = 10). The variability of the WDPT test accounts for a low correlation coefficient (r^2 = 0.51) when developing a regression function for soil contact angle and WDPT (Figure 16) (Table 6). Research by Agee (1973) also found a correlation coefficient (r^2 = 0.62) too low to be useful for predictive purposes.

Contact angles measured were all between 55 and 90 degrees. This is related to a property of the equation used (Appendix II). If the heighth of rise for water is zero, then the measured angle will

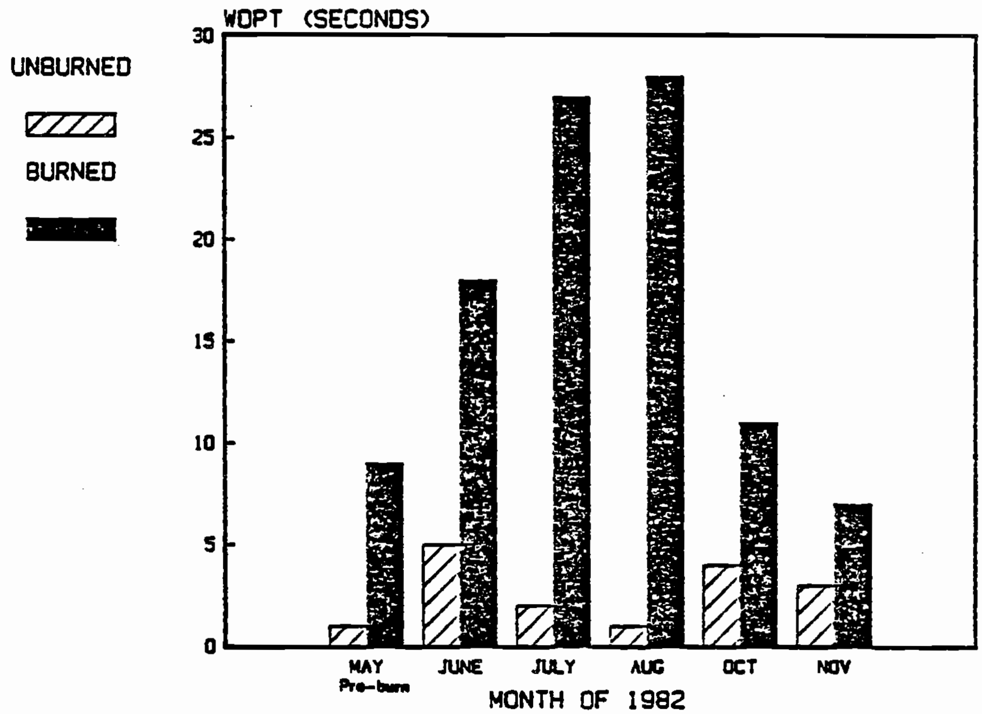


Figure 15. Comparison of burned and unburned water drop penetration times for the 0-5 cm soil depth at White Creek.

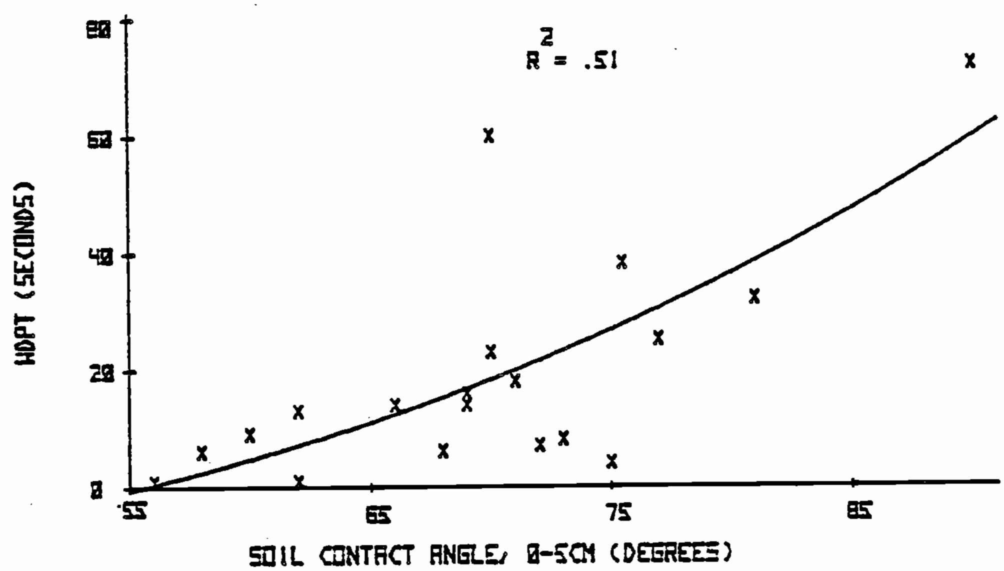


Figure 16. White Creek regression function for soil contact angle at 0-5 cm depth vs. the water drop penetration time.

TABLE 6

Regression models significant at a = 0.05 for the White Creek site, which have Soil Contact Angle (0-5 cm) as the independent variable (x).

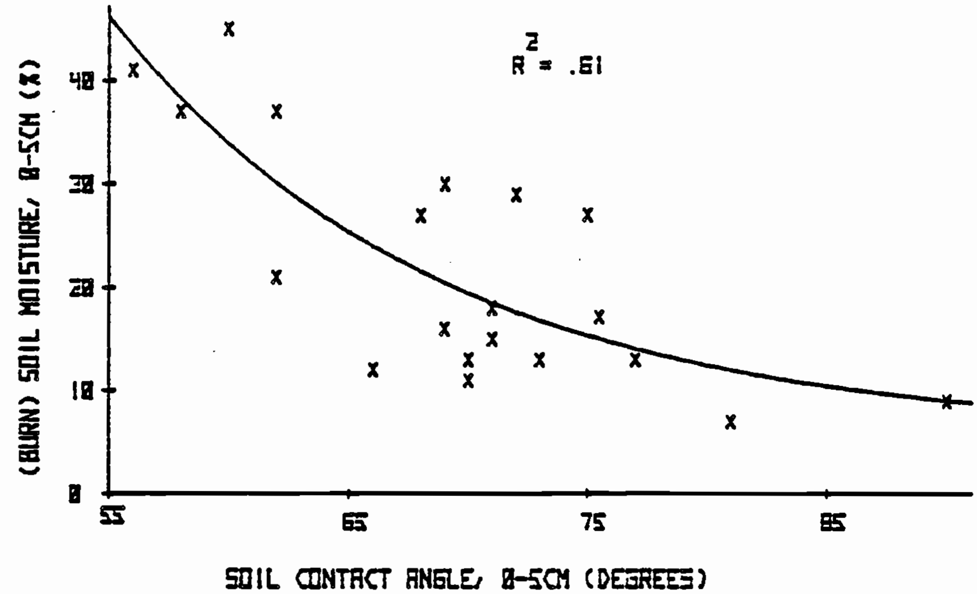
Dependent Variable (y)*	Model	F Statistic	r^2	n	Figure No.
1st Infiltration Run	$y = \frac{1}{0.085 + (3.5)(10^{-4})(1.08^{x})}$	251.0	0.93	20	20
2nd Infiltration Run	$y = 9.52 + (116.5)(0.93^{x})$	29.9	0.62	20	20
1st minus the 2nd Infiltration Run	$y = \frac{L_n N \frac{1}{0.9 + (37.7)(10^{-9})(1.2^{x})} 0}{0.18}$	97.6	0.92	20	21
Water Drop Penetration Time	$y = (10.7)(10^{-5})\ x^{3} - 18.4$	18.9	0.51	20	16
Soil Moisture, 0-5 cm	$y = 5.9 + (2181)(0.93^{x})$	29.1	0.61	20	17

* units: contact angle (degress), infiltration (cm/hr), water drop penetration time (seconds), soil moisture (percent).

be 90 degrees regardless of the heighth of rise for ethanol. For the angle to approach 0 degrees, the heighth of rise for water must be approximately 2.5 times higher than for ethanol. If the glass tubes were long enough to allow letting the fluids rise for a week or better, it may have been possible to obtain a contact angle lower than 55 degrees. However, the tubes would need to be at least 3 times longer and it is doubtful that the measured angle would be much less than 55 degrees. Past research in which this method was used by Kraemer and Hermann (1979), Debano (1966). Agee (1973), and Letey (1962) found measured contact angles to range from 45 to 90 degrees for a variety of soil types.

In the burned section, 75 percent of the soil samples taken from the 0-5 cm depth of soil had contact angles measured above 65 degrees. Ninety percent of the contact angles measured at the 5-15 cm and 15-30 cm depths in both burned and unburned treatments, were between 58 and 63 degrees. This agrees with results from the laboratory WDPT in identifying the 0-5 cm soil depth as the only depth which showed significant changes in wettability after burning (Figure 17).

Contact angles measured at 0-5 cm soil depth in the unburned section ranged from 55 to 70 degrees with 85 percent of the values between 55 and 65 degrees. In both the burned and unburned sections the higher values were obtained from soil samples measured during the months of July and August. The moisture content of the soil was also



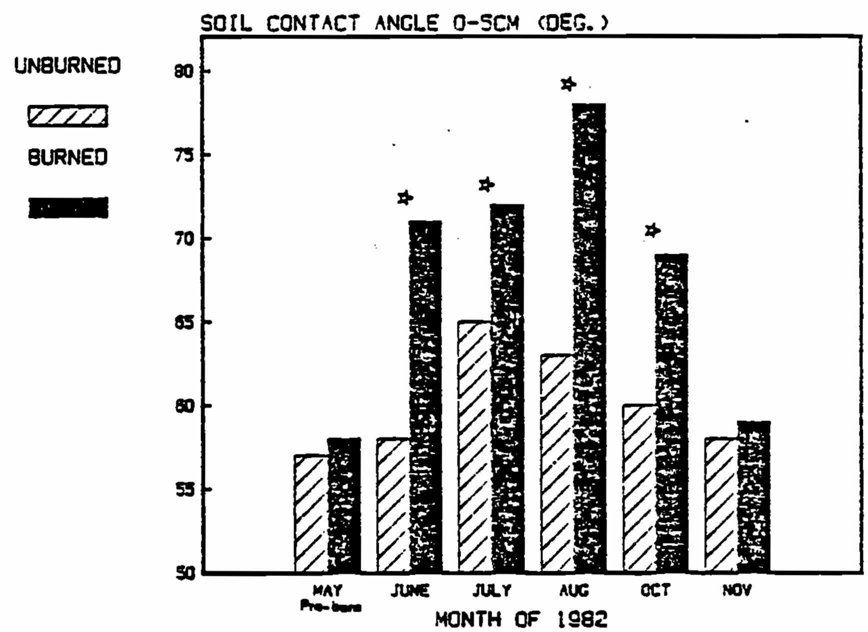


Figure 17. White Creek regression function for soil contact angle at 0-5 cm depth vs. the percent soil moisture, and comparison of burned and unburned soil contact angles at the same depth.
☆ - indicates a significant difference at $\alpha = 0.05$.

lowest during these two sample periods (Figures 8 and 9). DeBano (1969) found soil moisture content to be inversely related to the apparent liquid-solid contact angle. Although naturally occurring soil water repellency has been most commonly linked to leachates from resinous leaves and fungi, an alternate mechanism could be the heat-induced chemical change of some substances to a more hydrophobic state. A reaction that might occur is an initial dehydration of certain substances wherein hydroxyl groups are driven off as water, thus increasing the hydrophobic character of the material (Savage et al., 1969). As stated earlier, this was not observed after oven drying. Therefore, an interaction of prolonged soil dehydration and leachates from resinous leaves and fungi is suspected to cause the slight decreases in soil wettability observed in the unburned section.

In the burned section, soil contact angle increases were much greater, due to broadcast burning. Decreases in soil moisture correlated with increases in the measured contact angle at the 0-5 cm depth (Figure 17) (Table 6), but this relationship is due to soil moisture readily evaporating from water repellent soil.

Differences between contact angles measured in the burned vs. the unburned section were significant during all but the last sample period (November) following the burn. The mean for the burned section in November was less than one degree greater than the mean contact angle measured in the unburned section.

Recovery to Pre-Burn Levels

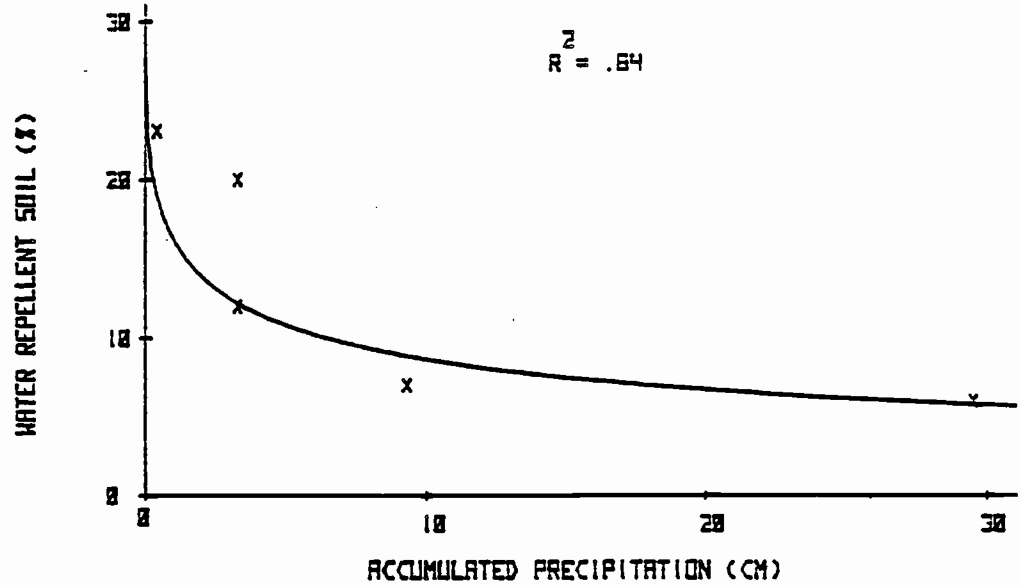
All parameters used to describe soil wettability (WDPT, contact angle, surface repellency) did not reveal a significant difference between the burned and unburned section during the last sample period in November. Therefore, it was assumed that soil wettability, when considering the entire site, had recovered to pre-burn levels. Isolated spots in plot number two were still water repellent at the 0-5 cm depth of soil, but none of these were extensive and totalled 25 percent of the entire plot. DeByle (1973) found water repellency to persist for one year following a prescribed burn in Montana, and DeBano and Rice (1973) suggest that the effect of water repellency on vegetation or hydrology of a site is greatly reduced after the first year and becomes negligible after 5 to 10 years.

Soil weathering processes such as vegetative growth, freezing and thawing, and leaching by rainfall, are involved in the removal of a repellent layer. Root extension from fast growing vegetation on a burned site, provides channels in the soil for moisture to bypass a repellent layer. Vegetation also stores some precipitation so it can be much more slowly transmitted to the soil surface. In this way, moisture from above and below a repellent layer can slowly move to the dry soil and thus overcome the hydrophobic tendency. Freezing and thawing aides this process by creating many large pores in the surface 5 cm of soil, which reduces the effect rainsplash may have on plugging macropores. In summary, vegetative growth, plus freezing and thawing are processes which aide moisture to infiltrate a repellent layer and leach hydrophobically coated soil particles.

As the water repellency recovered to pre-burn levels, a substantial regrowth of vegetation occurred (Figure 10). In addition, some freezing and thawing of the surface 5 cm of soil was evident one day prior to the November sample period. Temperatures at Cave Junction reached a low of -2°C (28°F) during the early morning hours.

Since freezing conditions only occurred before the last sample period, and measurements were not taken on vegetation regrowth, precipitation was investigated as an independent variable which would induce soil wettability to recover to pre-burn levels.

Historically, daily precipitation in southwest Oregon is slight during the summer months and does not begin to reach high daily and monthly accumulations until October. Although rainfall intensity is low, southwest Oregon may experience storms of long duration with at least 15 days of measurable precipitation per month from October to May (Froehlich et al., 1982). As southwest Oregon experienced the change from dry season to rainy season, soil water repellency decreased in the burned section. Reductions in soil contact angles (0-5 cm) and surface water repellency were found to be correlated with the accumulated rainfall measured at Cave Junction following the burn (Figure 18) (Table 5).



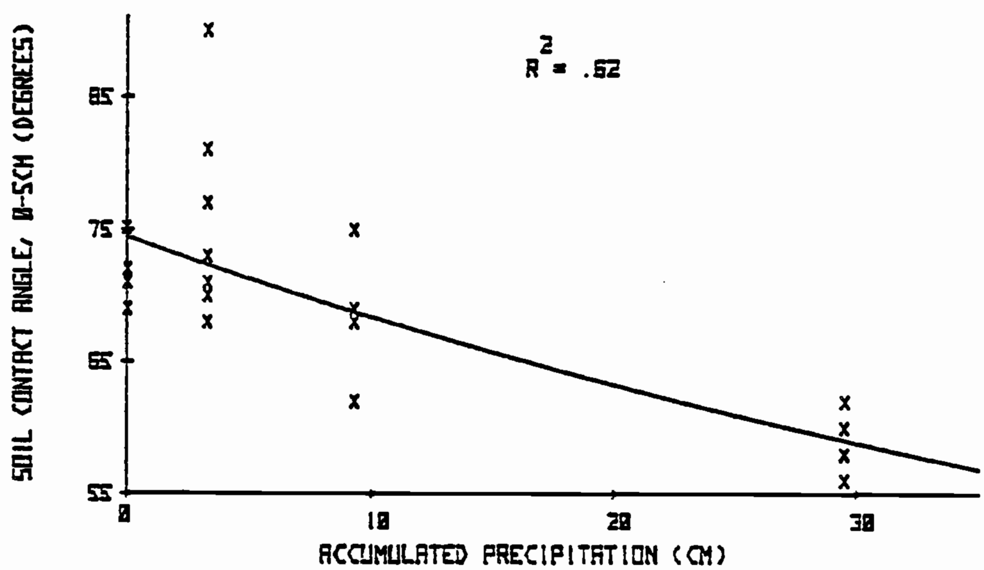


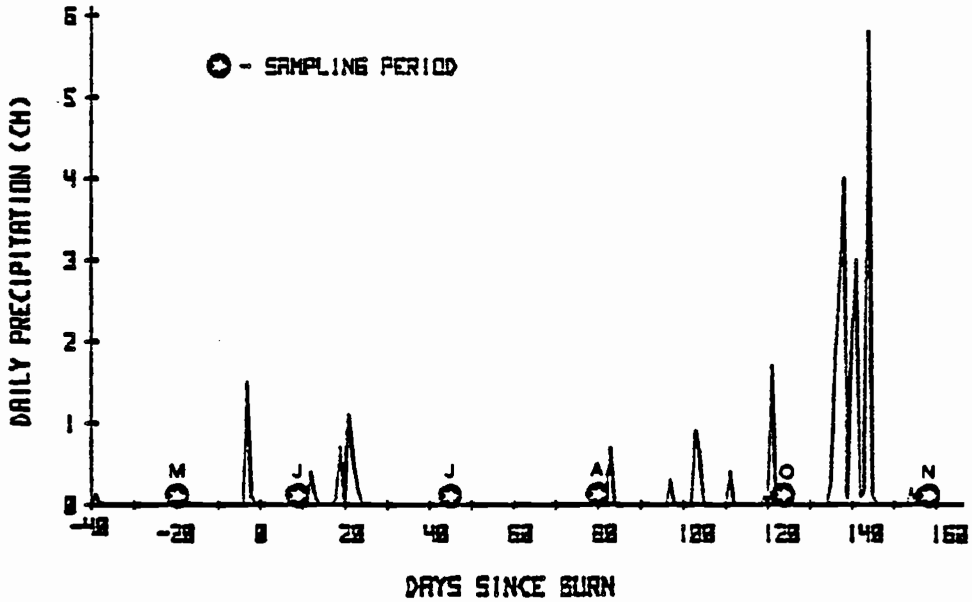
Figure 18. White Creek regression functions for the percent of water repellent soil and soil contact angle at 0-5 cm depth vs. the accumulated precipitation between soil sample periods.

Infiltration Rates

Burned vs. Unburned

The means of the first and second infiltration runs in the burned section of White Creek both showed significant differences when compared to means measured in the unburned section for the first three sample periods following the burn (June, July, and August). In addition, the second infiltration run also showed a significant difference during the fourth sample period in October (Figure 19). This is attributed to an intense, short duration precipitation event of 1.7 cm (0.68 inches), which occurred one day previous to measurements in October. The intense rainfall could have dislodged fine soil particles on the exposed mineral soil surface of the burned area. These, in turn, would seal macropores and temporarily reduce infiltration rates. During the first infiltration run, any remaining unplugged macropores may have become plugged, thus leading to a reduction in porosity near the soil surface before the second run. This resulted in a decrease in the infiltration rate at the saturated soil surface during the second infiltration run.

Several past studies refer to surface sealing, due to a high percentage of bare ground in burned areas, as a factor in reducing infiltration rates (Johnson and Beschta, 1980, Moldenhauer and Long, 1964, Austin and Baisinger, 1955, Wells et al., 1979). Duley (1939) postulated that this thin, compacted layer at the soil surface was



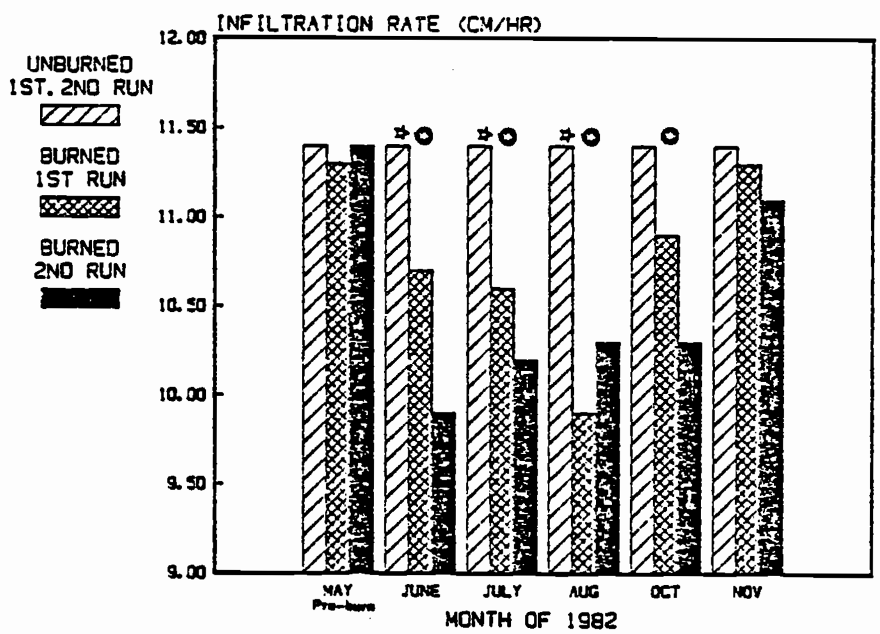


Figure 19. The daily precipitation pattern recorded at Cave Junction, and comparison of burned and unburned infiltration rates at White Creek.
☆ ✪ - indicates a significant difference at $\alpha = 0.05$ for the 1st and 2nd Infiltration runs respectively.

apparently the result of severe structural disturbance due to the beating effect of the raindrops, followed by an assorting action as runoff transported fine soil particles over the surface and deposited them between larger ones. Moldenhauer and Long (1964) emphasized that a soil that has been sealed once by raindrop action and then dried will seal again rapidly when rain begins, and will reach equilibrium runoff rates quickly unless the seal has been broken up between rains.

Accumulated rainfall was greatest between the October and November sample periods (Figure 19). It is unlikely that the soil ever dried during this period of light and long duration storms. Surface sealing was not evident in November. Without excessive drying of the soil between shorter and more intense storms, small particles dislodged by rainsplash could not be "fixed" in macropores as the soil dries after they were deposited. Instead, the particles would be more mobile and water could infiltrate around them by cohesion or carry them down the steep slopes as suspended sediment. A more obvious factor in the destruction of surface sealing and increase in infiltration rates for November was the freezing and thawing process which occurred one day before infiltration was actually measured in November. This aided in breaking up surface sealing by opening large macropores.

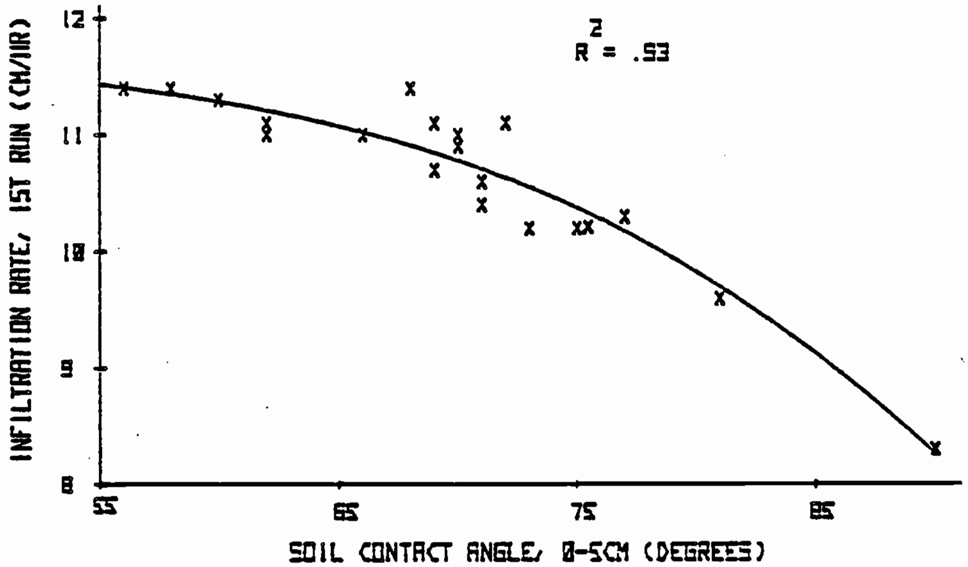
Runoff was not recorded in the unburned section for all but the October sample period, when one infiltration point was located on exposed soil. The small decrease in infiltration recorded was probably due to the same surface sealing that characterized the burned section in October. With a healthy population of residual shrubs, resprouting stumps, and a continuous cover of slash, very little of the mineral soil was exposed in the unburned section.

Without significant changes in soil wettability and a lack of variability in infiltration rates, it was not possible to develop statistical correlations for infiltration in the unburned section, but the burned section did reveal some strong associations.

Variation in Infiltration Rates

Some reasons previously discussed for decreasing infiltration rates after slash burning may include surface sealing due to rainsplash on exposed mineral soil, decreases in soil wettability, and increases in soil moisture content during the growing season following the burn. Of these three, soil wettability and moisture content were quantitatively correlated to the variability found in infiltration rates measured in the burned section.

The contact angle of soil samples taken at 0 - 5 cm depth was inversely correlated to the first (r^2 = 0.93) and second (r^2 = 0.66) infiltration runs (Figure 20). Multiple regression did not significantly improve the model for the first run, but adding soil moisture at a depth of 15 - 30 cm to the model for the second run resulted in a better correlation (r^2 = 0.72) (Table 6). The stronger correlation



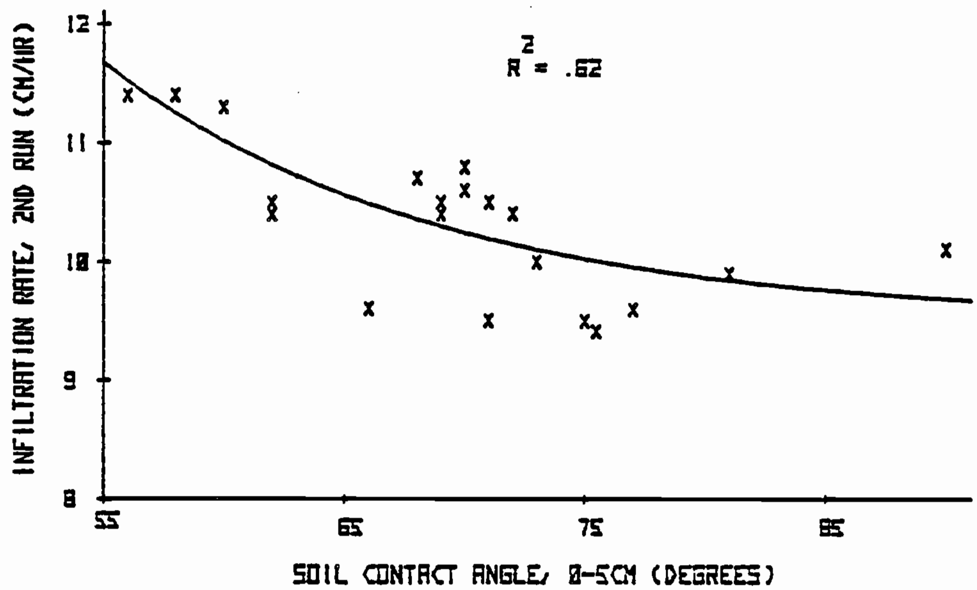


Figure 20. White Creek regression functions for the 1st and 2nd infiltration runs vs. soil contact angle at the 0-5 cm depth.

between contact angle and the first run of infiltration can be attributed to differences between unsaturated and saturated flow. When the first infiltration run begins, the soil is unsaturated and water enters the soil mostly in response to the attraction forces between the soil particles and water molecules (cappilary action). The attraction forces between the water and the soil can be represented by the contact angle. If soil particles become coated with hydrophobic substances and the contact angle increases, then the attractive forces decrease and the flow rate is consequently reduced. However, most of the water applied eventually entered the soil due to the discontinuous nature of repellent soils in an infiltration plot. Meeuwig (1971) observed different wetting patterns in repellent soils depending on size, continuity, and location of water-repellent zones. Infiltrating water can enter wettable spots, large macropores caused by animal activity, woody roots that have subsequently decayed (Aubertin, 1971), and/or freezing and thawing. After water has been absorbed, then some of the interfaces may coalesce and form a somewhat continuous layer of water having fewer interfaces to hinder liquid flow (DeBano, 1971). As the wet front penetrated the slowly - wettable 0-5 cm depth of soil, it entered the more absorbent soil below and the rate of advance increased. This process is contrary to the normal infiltration curve which show a reduction in infiltration rates as water is applied (Hillel, 1971) and explaines why the first run of infiltration was lower than the second run in August (Figure 19), when the soil contact angle was also the highest (Figure 17). Since infiltration curves were not developed in this study, the difference between the first and second infiltration run was correlated to the soil contact angle and indicates that a time dependent infiltration curve will be decreasing at low contact angles (wettable soil), but the curve will become increasing on soils with a high contact angle (water repellent) (Figure 21) (Table 6). Soils which are water repellent at the surface seem to behave similarly to compacted soils with respect to the shape of an infiltration curve. Cafferatta (1980) found infiltration to be initially low as simulated rainfall is first applied on compacted soil.

The steep slopes encountered in this study can lead to increased runoff on repellent soils during the first run by not allowing the water to pond in small depressions at the soil surface. The WDPT test indicated that water will infiltrate a "spotty" repellent soil if it is allowed to sit at the surface for an extended time period. Water that strikes inclined, repellent soil moves downslope. Eventually, small channels formed that quickly carried water to the collection can during the first run.

With the majority of the simulated rainfall entering the soil, the moisture content in the upper 0-5 cm increased toward saturation. Runoff was reduced as the number of channels allowing water to enter the soil increased.

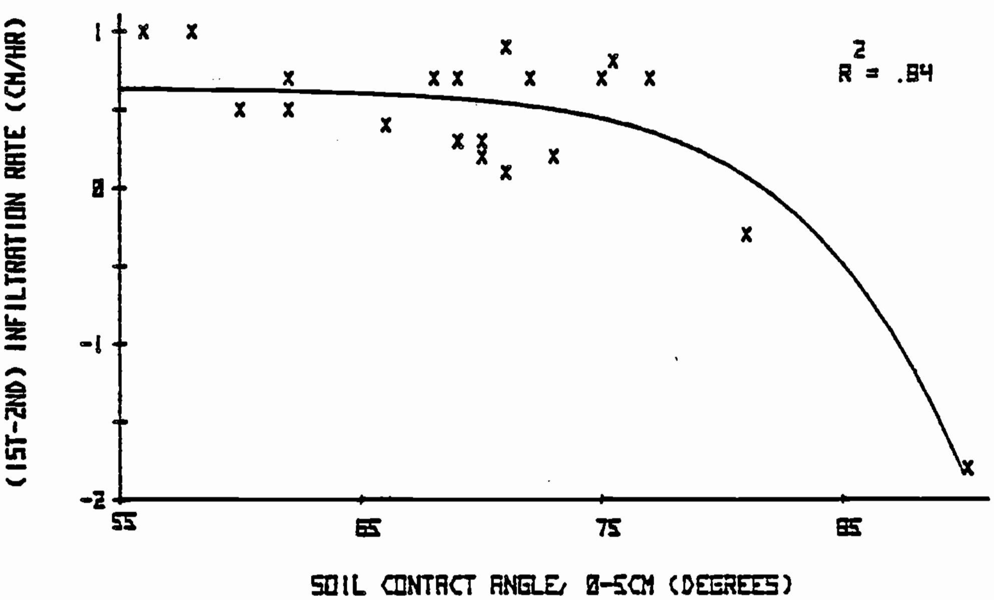


Figure 21. White Creek regression function for the 1st minus the 2nd infiltration run vs. soil contact angle at the 0-5 cm depth.

The 15 minute pause between the first and second infiltration run allowed water to drain into the profile and move in the 0-5 cm depth until the layer was more continuously saturated. The second infiltration run was then more strongly regulated by saturated flow, in which water flows through a soil in response to differences in water potentials. Saturated flow is regulated chiefly by the geometry of the saturated pores and by the liquid properties of the solution passing through the soil. This would indicate that deeply compacted soil or a high moisture content below the repellent soil layer would reduce infiltration rates measured during the second run. Why soil moisture at the 15-30 cm depth inversely correlated more strongly than the 5-15 cm depth, which was just below the repellent layer, is difficult to pinpoint. The wetting front probably did not reach the 15-30 cm layer until after the 15 minute pause between runs, thus giving this layer influence over downward water movement during the second run.

Although broadcast burning resulted in significantly reduced infiltration rates, the rates measured in the burned plots were not sufficiently low enough to produce appreciable overland flow. The lowest rate recorded during the first run was 5.3 cm/hr (2.1 inches/hr) in August and 8.4 cm/hr (3.3 inches/hr) for the second run in July. These minimum values are still greater than calculated values for a 100 year event of 2.9 cm/hr (1.2 inches/hr) (Miller et al., 1973) and 1.8 cm/hr (0.7 inches/hr). The latter being obtained from regressions of recorded precipitation at Kerby, Oregon.

Reliable precipitation information is seldom available for higher elevations in Southwest Oregon and many stations were not established until the past 10 years. Annual precipitation has been found to be considerably higher than previously though at higher elevations in the Siskiyou Mountains (Froehlich et al., 1982). This indicates that precipitation intensities for storms above a 10 year interval are probably much greater at higher elevations than currently calculated. Natural rain during an intense storm will also have a larger average drop size and more kinetic energy than simulated rainfall. Due to this, surface sealing may be greater, thus lowering the infiltration rate during a storm that endures longer than an artificial application of 20 minutes. With a larger value for a 100 year event and reduced infiltration from burning and surface sealing, the chances of runoff would greatly increase.

However, in this study a sizable event of approximately 9.0 cm/hr (3.5 inches/hr) or better during the normally dry summer months, would be necessary to induce appreciable runoff at White Creek. The chances of this are slight.

Recovery to Pre-Burn Levels

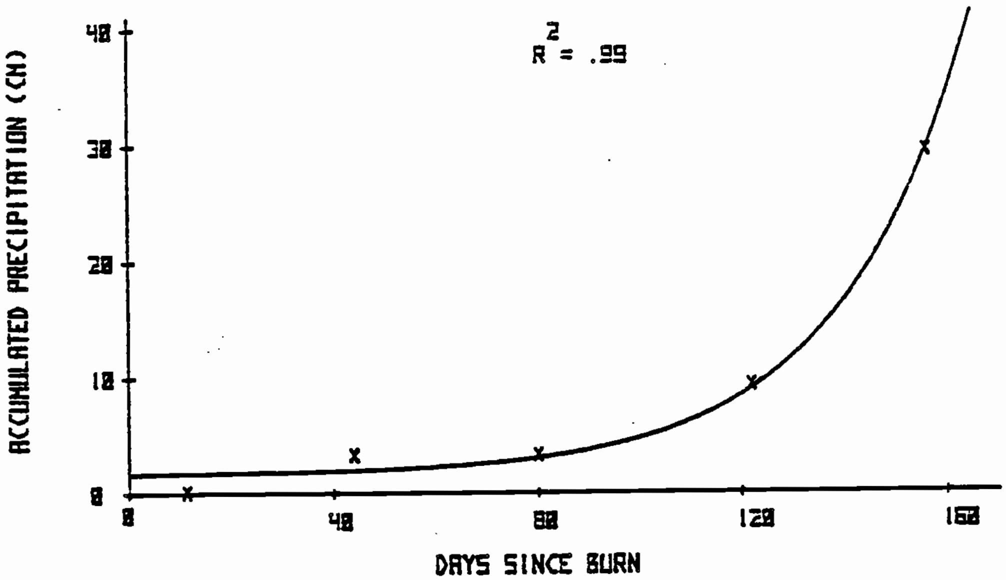
Infiltration rates recovered to pre-burn levels to the extent that there was no longer a statistically significant difference between the burned and unburned sections in November. Possible explanations for the recovery of infiltration rates are: (1) greater vegetative cover which protects the soil surface from sealing; (2) increases in soil wettability caused by rainfall leaching when soils are not allowed to dry out during periods of continuously light rain; (3) an increase in soil macropores attributed to vegetative root growth, animal activity, and freezing and thawing.

A correlation between the second infiltration run and the accumulated rainfall was found (Figure 22) (Table 5). The first infiltration run was too variable for a strong correlation. Although, rainfall is indirectly responsible for increases in infiltration, the vegetative growth and increases in soil wettability that are triggered by continuously light rain, represent the direct effect.

The association between rainfall and increasing infiltration is probably unique to sites which are burned early in the growing season. Infiltration can steadily recover exponentially as rainfall increases (Figure 22) (Table 5) throughout the growing season. The exception would be an intense storm immediately following the burn. Soil wettability and vegetative cover would be lowest and the potential for runoff would be greatest.

Comparison of White and Shan Creek Results

The more intense burn at Shan Creek did not show any overwhelming alterations in physical soil properties when compared to White



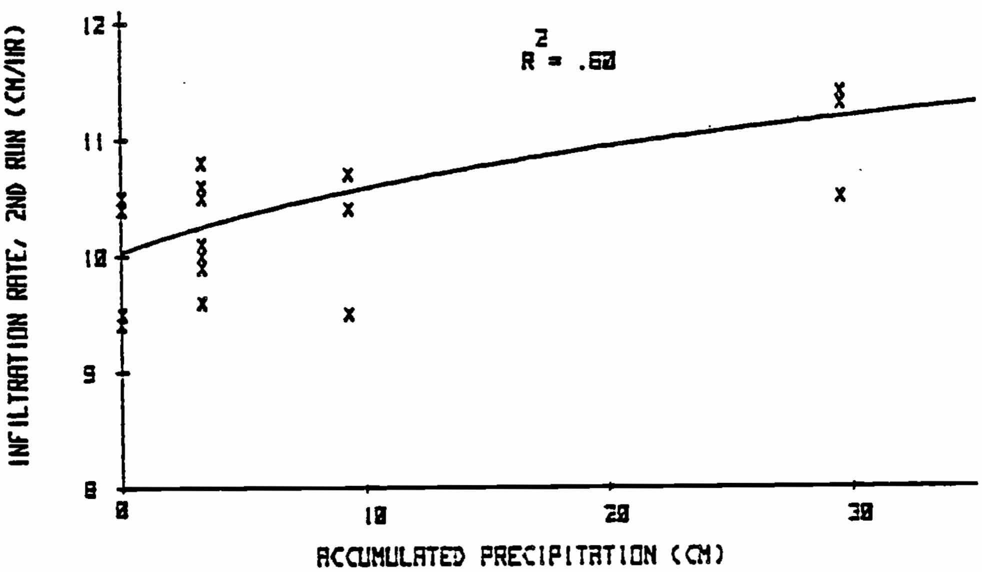


Figure 22. White Creek regression functions for the accumulated precipitation since the burn vs. time, and the 2nd infiltration run vs. the accumulated precipitation since the burn.

Creek (Figure 23). However, the slight difference in burn intensity did leave a greater percentage of exposed mineral soil, due to higher fuel consumption and less invading vegetation.

Repellency in Shan Creek was only found at the 0-5 cm depth of soil and was much more extensive than at White Creek (53% vs. 12%).This was undoubtedly the result of a higher consumption of litter during the burn, in which hydrophobic substances were more extensively volatilized and condensed on the mineral soil surface. Greater exposure of bare mineral soil and surface repellency is probably the reason for lower infiltration rates at Shan Creek, although the differences were not statistically significant.

Shan Creek had significantly higher soil moisture at the 5-15 and 15-30 cm depths. This may be a result of a longer dry spell before White Creek was measured and/or the noticeably greater presence of residual and invading vegetation at White Creek.

Infiltration measurements at Shan Creek reaffirmed the theory of increasing infiltration rates from the first to the second infiltration run on soils with a high contact angle and low moisture content. The August measurements at both sites reflected this tendency. As observed at the White Creek site, soil contact angles measured at 0-5 cm had the strongest influence on the first (r^2 = 0.85) and second (r^2 = 0.91) infiltration runs at Shan Creek (Figure 24) (Table 7).

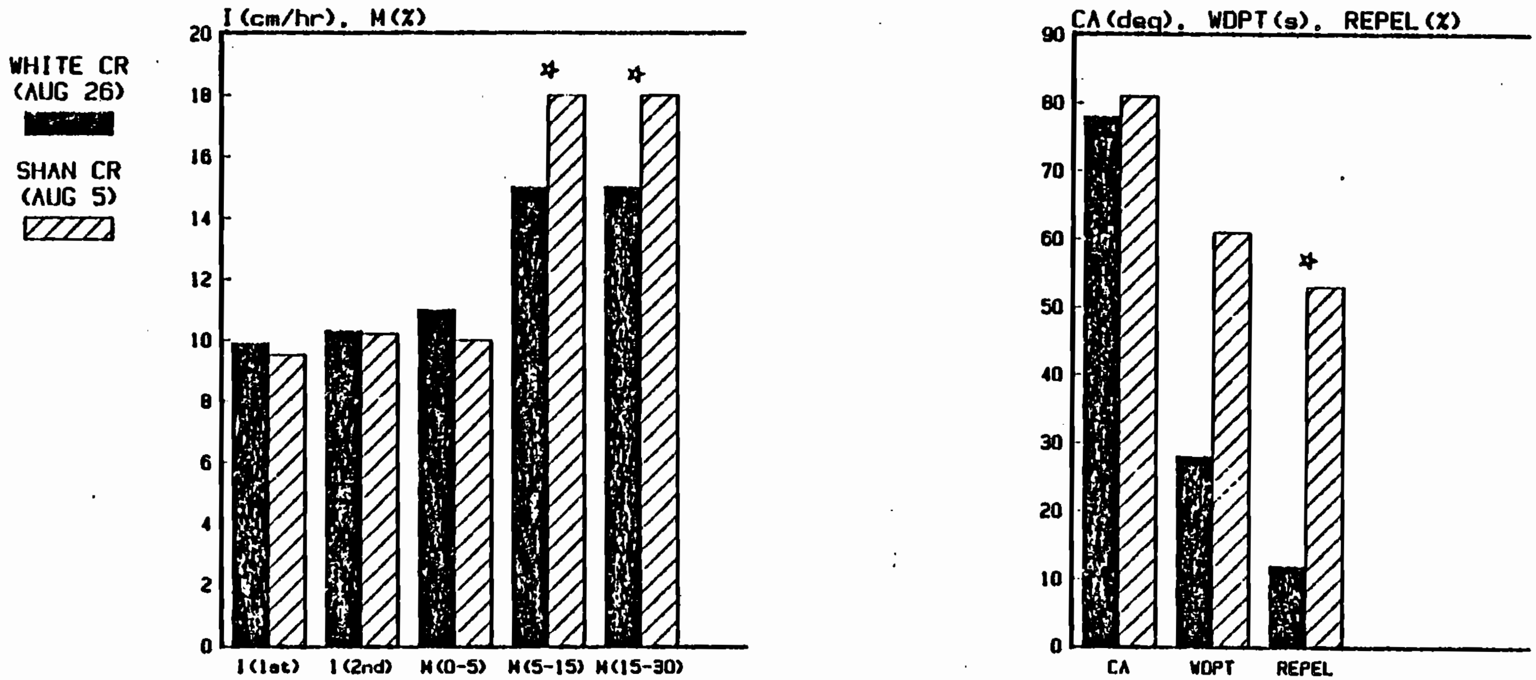
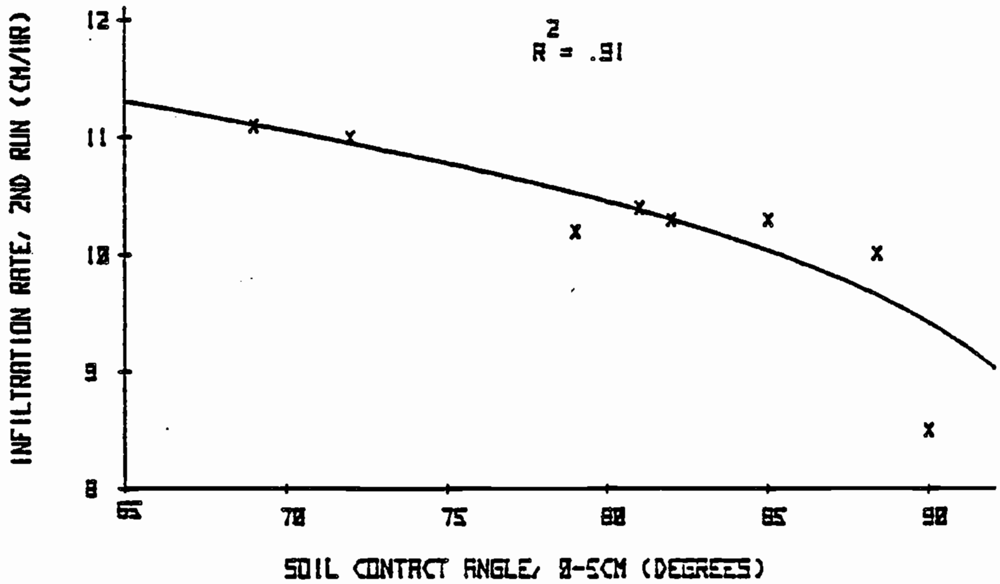


Figure 23. Comparison of variables measured on burned soils at White Creek vs. Shan Creek. (I-infiltration rate; M-soil moisture; A-soil contact angle, 0-5 cm; WDPT - water drop penetration time, 0-5 cm; REPEL - water repellent soil).
☆ - indicates a significant difference at $\alpha = 0.05$.



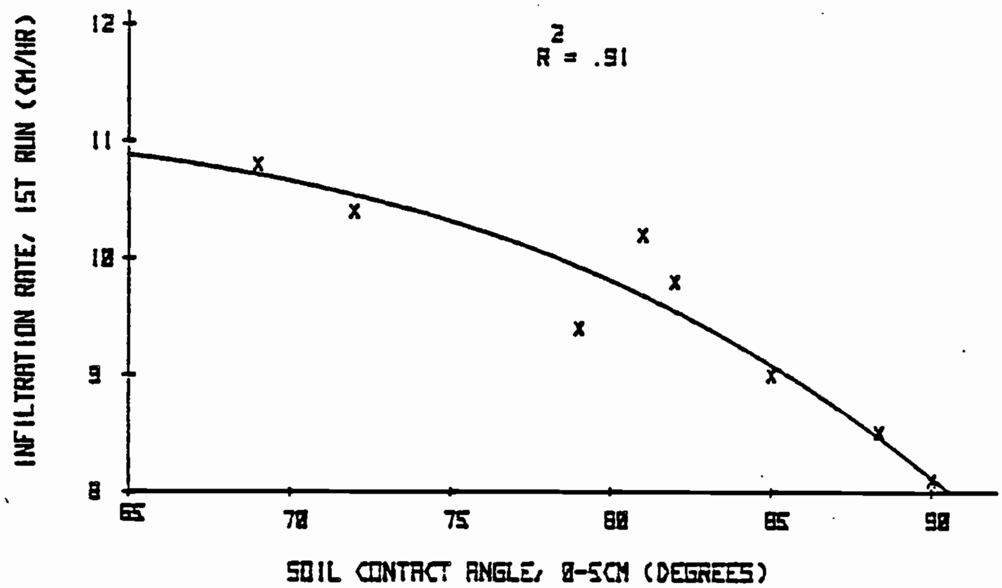


Figure 24. Shan Creek regression functions for the 1st and 2nd infiltration runs vs. soil contact angle at the 0-5 cm depth.

TABLE 7

Regression Models significant at $\alpha = 0.05$ for the Shan Creek site.

Variables in Regression*	Model	F Statistic	r^2	n	Figure No.
Soil Contact Angle, 0-5 cm (x) 1st Infiltration Run (y)	$y = \frac{1}{0.09 + (65.7)(10^{-7})(1.1^{x})}$	64.2	0.91	8	24
Soil Contact Angle, 0-5 cm (x) 2nd Infiltration Run (y)	$y = L_n[\frac{(16.1)(10^{6})}{x} - 166,586]$	60.8	0.91	8	24

* units: contact angle (degrees), infiltration (cm/hr).

In Summary, higher burn intensities at Shan Creek increased the amount of non-wettable soil, but this did not significantly alter soil moisture or infiltration rates. Past speculation indicates that severe burning could alter the hydrologic properties of soils, but at what point between moderate and severe burning this begins to become evident could not be determined in this study.

CHAPTER VII

CONCLUSIONS

The results of this study indicate that light-to-moderate broadcast burn intensities on steep slopes have a measurable effect on hydrological soil properties. However, these changes did not create any serious soil hydrological changes and were insignificant 5 months after burning.

Although infiltration rates were significantly reduced by broadcast burning, values were not recorded below the maximum 100 year precipitation event, calculated for both White and Shan Creek sites. While the burn intensity was higher at Shan Creek (moderate vs. light/moderate), infiltration rates did not significantly differ from those recorded at White Creek.

Reductions in soil infiltration rates were directly attributed to changes at the soil surface caused by burning. Removal of the vegetative cover exposed mineral soil to rainsplash, which caused surface sealing of macropores by fine particles, and consequently, reduced infiltration rates during the October sampling period at White Creek. Decreases in soil wettability were more consistently observed throughout the sampling periods. Immediately following burning 25% of the exposed mineral soil surface in the burned section at White Creek was water repellent, but this was reduced to 6% in November. Shan Creek had a significantly higher percentage, as 52%

of the exposed mineral soil surface was repellent 33 days following a broadcast burn. This change was probably caused by hydrophobic substances layers becoming volatilized during burning and in the litter and duff layers later condensing on soil particles near the surface. Burn intensities were not high enough for hydrophobic substances to penetrate lower than 5cm into the soil profile. Water repellent soil decreased infiltration by reducing the adhesive attraction between water and the surface of a dry soil particle. However, observed repellency was spotty or discontinuous and most of the water applied during rainfall simulation was able to enter the soil via adjacent wettable spots.

Due to the abundant presence of residual vegetation in the unburned section at White Creek, percent soil moisture during the summer was significantly lower when compared to the burned section. Soil moisture is seldom recharged during a typically dry summer in southwest Oregon. As the occurrence of precipitation increased during the fall and evapotranspiration demands decreased, soil moisture levels were nearly equal for both treatments. Slightly higher soil moisture during August at Shan Creek may have originated from a higher burn intensity, which consumed more existing vegetation.

When assessing the ramifications of various broadcast burn intensities, the land manager must consider fuel loading, climate, soils, vegetation, and topography indigenous to each site in question. There is a fine line between burning hot enough to satisfactorily reduce competing vegetation and slash loading vs. burning too hot and causing serious alterations of soil hydrological properties, which may lead to soil erosion. Selecting the proper intensity that will meet management objectives can vary among sites. Burning one day after a light spring rainstorm at White Creek resulted in soil antecedent moisture levels which could protect the soil resource and still allow the burn intensity to be hot enough to consume slash and competing vegetation. Therefore, a practical suggestion may be to burn when soil moisture is at the highest possible level that will still allow the fire to consume most of the slash and residual vegetation. A more complete investigation involving a variety of sites and burning intensities needs to be conducted before we can fully understand the effects of burning on the physical soil resource in southwest Oregon.

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APPENDICES

APPENDIX I.

Description of Soil series numbers 370, 382, 371, 718, and 701 (deMoulin, et al., 1975).

370 SERIES

The 370 series consists of deep, very gravelly, loamy, well-drained soils from sedimentary and metamorphic rocks in areas receiving over 35 inches of precipitation. They occur on moderately steep to steep and very steep mountainous slopes.

Profile Description: 370 gravelly loam.

Surface Soil:	0-8"	Very dark grayish brown, gravelly loam, friable, medium acid. 2-10" thick.
Subsoil:	8-45"	Brown, very gravelly loam, friable, medium acid. 30-50" thick.
Substratum:	45"+	Fractured metamorphic bedrock.

Variations: Depth to bedrock ranges from 40 to more than 60 inches. Coarse-fragment content ranges from 35 to 75 percent. Surface soil colors are very dark brown, dark brown, or very dark grayish brown. Subsoil colors are dark brown, brown, dark yellowish brown, or strong brown. Surface textures are silt loam, gravelly silt loam, loam, or gravelly loam. Subsoil textures are very gravelly silt loam, very gravelly loam, or very gravelly light clay loam.

Setting: The 370 soils occur on moderately steep to very steep sideslopes of the Siskiyou Mountains at elevations of 1,500 to 4,000 feet. Areas below 2,500 are on north-facing slopes. Slope gradients range from 10 to 85 percent but most are steeper than 35 percent.

Soil Behavior: The 370 soils are forested with a dominant overstory of Douglas-fir. Mixed stands, including pine and hardwood species, generally occur where there is less available soil moisture, although big-leaf maple indicates more moist spots. Available moisture content is mainly affected by the amount of coarse fragments in the soil profile. Other factors, such as plant competition, depth and aspect, are important. Site class is higher where water seeping from rock strata keeps the subsoil, or rooting zone, moist during the growing season. Waterholding capacity is low.

Conditions that affect the success of regeneration are the amount of coarse fragments in the surface layer and the kind and amount of plant competition. The regeneration hazard generally is slight. When total plant cover is removed, soil material is washed away, leaving gravel and cobbles on the surface that hinders reestablishment of trees. Brush is a strong competitor for available moisture where annual precipitation is high.

Loss of organic matter in the thin surface layer by scalping will drastically lower productive capacity. Cable yarding should be used on slopes greater than 35 percent. Tractor yarding on more gentle slopes usually will not cause adverse compaction because of dominantly loamy soils with a high coarse-fragment content. Benched and concave slopes should be avoided when the soils are wet. Water bars for erosion control are very difficult to construct on steep slopes in this gravelly, loamy material.

Moisture content, depth of excavation and position on slope are important factors influencing stability of these soils. Some raveling occurs on deep cut slopes. Small pockets of 370 soils will slump onto roadways when excavated. Massive slides may occur when they become saturated. Seeps and springs are common in large bodies of 370 soils. Small drainageways contain water late into the dry season.

382 SERIES

The 382 series consists of deep, red, clayey, very gravelly, well-drained soils from metamorphic and sedimentary rocks in areas receiving more than 35 inches of precipitation. They occur on strongly sloping to very steep mountainous slopes.

Profile Description: 382 gravelly clay loam.

Surface Soil:	0-9"	Dark reddish brown, gravelly clay loam, friable, slightly acid. 5-15" thick.
Subsoil:	9-48"	Yellowish red, very gravelly clay loam, firm, very sticky, very plastic, medium acid. 25-59" thick.
Substratum:	48"+	Fractured metamorphic rocks.

Variations: Depth to bedrock ranges from 40 to 60+ inches. Coarse-fragment content ranges from 35 to 75 percent. Surface colors are dusky red, dark reddish brown, or very dark brown. Subsoil colors are dark reddish brown, dark red, red, reddish brown, or yellowish red. Surface soil textures are gravelly loam, gravelly clay loam, very gravelly loam, or very gravelly clay loam. Subsoil textures are very gravelly clay, or very cobbly clay.

Setting: The 382 soils occur on strongly sloping to very steep slopes in the Siskiyou Mountains at elevations of 1,500 to 4,000 feet. Most areas below 2,500 feet are on north-facing slopes. Gradients range from 10 to 85 percent, with slopes of 10 to 65 percent being most common.

Soil Behavior: The 382 soils are forested with mixed stands of conifers and hardwoods. Douglas-fir, ponderosa pine, madrone, tanoak and chinquapin are the dominant tree species. Hardwoods and drought-resistant species are more abundant where gravel content of soil is higher, on southerly aspects or where annual precipitation nears 35 inches. Site class is higher on benches and on lower slope positions that receive moisture by seepage.

Bare-root plantations are moderately successful but failure can be expected where a thick layer of gravel occurs on the surface. Brush competition is greater in high-precipitation zones.

The compaction hazard is moderate to severe, and heavy equipment usage during wet soil conditions will lower productivity and increase surface erosion. Some concave and benched slopes remain moist in the surface foot of soil throughout the year and should be avoided.

Cable yarding can be safely accomplished most of the time. Water bars can be effectively constructed where slope gradients do not exceed 35 percent.

Excavation reduces mantle stability and slumping of cut slopes can be expected. Landslides will occur more often where deep cuts are made, where surface runoff concentrates and near seeps and springs.

371 SERIES

The 371 series consists of moderately deep, very gravelly, loamy, well-drained soils from metamorphic rocks in areas receiving more than 35 inches of precipitation. They occur on steep to very steep mountainous slopes.

Profile Description: 371 gravelly loam.

Surface Soil:	0-7"	Very dark grayish brown, gravelly loam, friable, medium acid. 2-10" thick.
Subsoil:	7-35"	Brown, very gravelly loam, friable, medium acid. 10-35" thick.
Substratum:	35"+	Fractured metamorphic bedrock.

Variations: Depth to bedrock ranges from 20 to 40 inches. Coarse-fragment content ranges from 35 to 75 percent. Surface soil colors are very dark brown, dark brown, or very dark grayish brown. Subsoil colors are dark brown, brown, dark yellowish brown, or strong brown. Surface textures are silt loam, gravelly silt loam, loam, or gravelly loam. Subsoil textures are very gravelly silt loam, or very gravelly loam.

Setting: The 371 soils occur on steep to very steep sideslopes of the Siskiyou Mountains at elevations of 1,5000 to 4,000 feet. Areas below 2,500 feet are on north-facing slopes. Slope gradients range from 35 to 85 percent.

Soil Behavior: The 371 soils support a mixed stand of conifer and hardwood species. Douglas-fir and ponderosa pine are dominant. Madrone, black oak and tanoak become more abundant where available soil moisture for plants is less. This is usually on steeper slopes, southerly aspects and near zones of lower rainfall. Available moisture is mostly affected by the amount of coarse fragments in the soil profile and depth of soil. Productivity is low and directly affected by these factors. Available water-holding capacity is low. The regeneration hazard is severe.

Large amounts of coarse fragments in the surface layer restrict the success of bare-root plantings. Removal of plant cover will result in a loss of soil material by erosion and the buildup of coarse fragments. This reduces water-storage capacity as well as productivity.

Cable yarding causes the least disturbance of the surface layer. Although tractor logging does not adversely affect soil structure, bare soil in skid trails is a source of stream pollution. Construction of effective water bars is very difficult on steep slopes in this very gravelly, loamy material.

Cut-slope stability is good but minor failures may occur where the bedrock is highly fractured or where rock layers are inclined toward the excavation. Some slumping of the soil mantle onto the roadway may occur.

718 BEEKMAN SERIES

THE (718) Beekman series consists of moderately deep, loamy, very gravelly soils from metamorphic rocks in areas receiving less than 35 inches of precipitation. They occur on mountainous slopes in the Siskiyou Mountains.

Profile Description: (718) Beekman very gravelly loam.

Surface Soil:	0-8"	Dark brown, very gravelly loam, friable, neutral. 6-18: thick.
Subsoil:	8-34"	Brown, very gravelly loam, friable, slightly acid. 12-32" thick.
Substratum:	34" +	Fractured bedrock.

Variations: Depth to bedrock ranges from 20 to 40 inches. Coarse-fragment content ranges from 35 to 75 percent. surface soil colors are dark brown, brown, or grayish brown. Subsoil colors are dark yellowish brown, brown, or reddish brown. Subsoil colors are dark yellowish brown, brown, or reddish brown. Textures are very gravelly loam, or very gravelly clay loam. The soils are slightly acid to neutral.

<u>Setting:</u> The (718) Beekman soils occur on moderately steep to very steep mountainous slopes are elevations of 1,000 to 4,000 feet. Areas above 2,500 feet generally are on south-facing slopes. slope gradients range from 20 to 85 percent with 35 to 85 percent slopes being most common. The soils formed in colluvium from metamorphosed sedimentary and volcanic rocks.

The summers are warm and dry and the winters are cool and moist. Mean annual precipitation ranges from 20 to 35 inches. The mean annual temperature is 48 to 54 degrees F.; the mean January temperature centers on 35 degrees F.; and the mean July temperature centers on 72 degrees F. The frost-free period ranges from 140 to 180 days. Native vegetation consists of madrone, ponderosa pine, Douglas-fir and an understory of shrubs, forbs and grasses.

The (718) Beekman soils are associated with the shallow, very gravelly 701 soils: the moderately ddep, loamy (781) Colestine soils; and the deep, clayey, reddish (719) Manzanita series. Adjacent areas receiving more than 35 inches of precipitation have soils of the shallow 372 series, the moderately deep 371 series and the deep 370 series, all of which are very gravelly.

The (718) Beekman soils differ from the (781) Colestine soils by containing more than 35 percent coarse fragments. They differ from the 371 soils from metamorphic rocks and the 731 soils from volcanic rocks by being less acid, or higher in bases.

Soil Behavior: The (718) Beekman soils have a low production capacity fro conifers on northerly aspects. They support scrubby conifers mixed with hardwood species on southerly aspects and mostly brush and grass near drier zones.

Regeneration by bare-root planting is very difficult because of low annual precipitation, low soil moisture availability and grass competition. Some success will occur at higher elevations and near zones of higher precipitation. Removal of plant cover by excessive disturbance results in loss of soil material and buildup of coarse fragments, thus limiting water-storage capacity as well as lowering productivity.

Cable yarding causes the least disturbance of the surface layer. Although tractor logging does not adversely affect soil structure, erosion susceptibility is severe and bare soil in skid trails is a source of stream pollution. Construction of effective water bars is nearly impossible on steep slopes in this very gravelly, loamy material.

Cut-slope stability is high but minor failures will occur where the bedrock hs been highly fractured or where rock layers are inclined toward the excavation. Some slumping of the soil mantle onto the roadway will occur.

Excavation on steep slopes will result in fractured substratum material covering the surface of fill slopes. this coarse rock material is not a suitable seedbed and will remain devoid of vegetation for several years. Most roadbeds will be in the rock substratum and surfacing in sime places may not be necessary. On very steep slopes, side-cast material will extend far downslope and damage productive land.

701 SERIES

The 701 series consists of shallow, very gravelly, well-drained soils from metamorphic rocks in areas receiving less than 35 inches of precipitation. They occur on steep to very steep slopes.

Profile Description: 701 very gravelly loam.

Surface Soil:	0-4"	Brown, very gravelly, loam, friable, slightly acid. 6-18" thick.
Subsoil:	4-13"	Brown, very gravelly loam, friable, slightly acid. 6-18" thick.
Substraturm:	13"+	Fractured metamorphic rock.

Variations: Depth to bedrock ranges from 12 to 20 inches. Coarse-fragment content ranges from 35 to 70 percent. Surface soil colors are dark brown, brown, or reddish brown. subsoil colors are brown, strong brown, or yellowish red. Textures of the surface and subsurface layers are loam or clay loam.

Setting: The 701 soils occur on steep to very steep foothills at elevations between 1,200 and 4,000 feet. Most areas are on south-facing slopes. Slope gradients range from 35 to 85+ percent. The soils formed in colluvium from medisedimentary and medivolcanic rocks.

The summers are warm and dry and the winters are cool and moist. Mean annual precipitation is 20 to 35 inches. The mean annual air temperature ranges from 45 to 54 degrees Fl; the mean January temperature centers on 37 degrees F.; and the mean July temperature centers on 70 degrees F. The frost-free period ranges from 120 to 180 days. Vegetation is oak, madrone, ponderosa pine, poison oak and grass.

The 701 soils are associated with the moderately deep, very gravelly (781) Colestine soils; and (R) rock land. Adjacent soils in areas receiving more than 35 inches of precipitation include those of the shallow, very gravelly 372 series and the moderately deep, very gravelly 371 series.

The 701 soils differ from the shallow (36) Witzel soils by being lighter colored and from the shallow 372 and 732 soils by being less acid.

Soil Behavior: Soils of the 701 series are extremely droughty and have a low capacity to produce timber. The soils support mixed stands of hardwoods and conifers on northerly aspects and mostly open grassland or brush on southerly aspects. site class for Douglas-fir is very low.

Bare-root regeneration hazard is severe because of low annual precipitation, very low soil mosture availability and grass competition.

Timber harvest on these soils will result in exposed areas which are susceptible to erosion. Excessive slope gradients and shallow, gravelly soil profiles do not permit construciton of effective water bars.

Roads are stable. Side-cast material usually extends far downslope and contains mostly fractured rock. A vegetative cover is difficult to establish in this material. Roadbeds are in the rocksubstratum and surfacing may not be necessary. Good construction rock occurs in the substratum of the 701 soils. Bedrock can be ripped in many placesbut blasting may be necessary near rock outcrop.

Appendix II. Derivation of the Capillary Rise Equation for use in estimating the liquid-solid Contact Angle (Letey, 1962).

1. The Capillary Rise equation for water and ethanol respectively:

$$h_w = \frac{2\ \gamma_w \cos\ \Theta}{\rho_e\ g\ r} \qquad\qquad h_e = \frac{2\ \gamma_e \cos\ \Theta}{\rho_e\ g\ r}$$

2. Since ethanol with result in complete wetting of capillary tubes:

$$\Theta = 0 \qquad \text{and} \qquad \cos\ \Theta = 1$$

Therefore: $$h_e = \frac{2\ \gamma_e\ (1)}{\rho_e\ g\ r}$$

Rearranging the equation: $$r = \frac{2\ \gamma_e}{\rho_e g\ h_e}$$

3. If both soil samples are equally packed in their respective glass tubes, then the average pore radius (r) will be equal in both equations.

By substitution: $$h_w = \frac{2\ \gamma_w \cos\ \Theta}{\rho_w\ g\left(\frac{2\ \gamma_e}{\rho_e\ g\ h_e}\right)}$$

Reducing the equation: $$h_w = \frac{\rho_e\ h_e \cos\Theta\ \gamma_w}{\rho_w\ \gamma_e}$$

Rearranging: $$\cos \theta = \frac{\rho_w \gamma_e h_w}{\rho_e \gamma_w h_e}$$

Simplifying: $$\theta = \cos^{-1} (\text{constant}) \left(\frac{h_w}{h_e}\right)$$

h_w - height of water rise

h_e - height of ethanol rise

ρ_w - density of water

ρ_e - density of ethanol

γ_w - surface tension of water

γ_e - surface tension of ethanol

r - effective pore radius

θ - Contact Angle or "Capillary Rise Index"

APPENDIX III

Procedure used to determine soil texture (Froehlich, 1978)

Hydrometer analysis:

add 50 ml of 6% hydrogen peroxide, swirl occasionally

let stand 8 hr

dry overnight at 105°C

obtain dry weight to nearest 0.01 g

add 125 ml of sodium pyrophosphate solution (5%), stir

let stand 24 hr

add distilled water to make a slurry (200 mls)

rinse into sedimentation cylinder

disperse with a malt mixer for 2 minutes, add a few drops amyl alcohol as necessary to control foam

fill sedimentation cylinder to 1000 ml with distilled water

if sample contains particles with appreciable internal porosity, invert to mix then let stand a few hours

measure temperature of mixture

invert and reverse 60 times in 1 min then place right side up and record time

add 2-3 drops amyl alcohol as necessary to remove foam

to take hydrometer reading, begin to slowly insert hydrometer 20 s before appointed time, read to top of meniscus, and then immediately remove hydrometer and swirl clean in a jar of distilled water

take readings after: 1, 4, 15, 30, 60, and 120 minutes

ascertain temperature of solution again before last two readings

prepare blank with dispersant and water only and read hydrometer and temperature on that as well

record: original dry weight (W_s) of sample after H_2O_2 treatment

zero correction (on blank, 0-60 = +, < 0 = -)

actual hydrometer reading

corrected hydrometer reading

reading corrected for meniscus only

L from table (based on hydrometer reading corrected for meniscus only)

K from table (based on particle density and temperature)

calculate:

percent finer (% remaining at hydrometer level) =

$$\frac{\text{Corrected Hydrometer reading}}{\text{Wt. of soil after } H_2O_2} \times 100$$

diameter =

$$K \sqrt{\frac{L}{\text{time (min)}}} \quad \text{(mm)}$$