Design and installation of a study to determine the effect of multiple logging roads on the soil mantle hydrology of a spruce-fir forest
by Edward Robbins Burroughs

A thesis submitted to the graduate faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Civil Engineering
Montana State University


Abstract:
The U. S. Forest Service, Interountain Forest and Range Experiment Station, initiated a study in 1960 of the effect of multiple logging reads on the soil mantle hydrology of a spruce-fir forest. Two types of logging roads, insloped and outsloped, were identified by disposition of drainage water. The study objectives were: 1. To measure the effect of insloped and outsloped roads on soil moisture in area-inches of water.

2. To determine if the influence of roads on soil moisture is intensified by roads built one above the other on the site.

3. To determine the increase in soil moisture, in area-inches of water, by clearcutting timber on both roaded and unroaded sites.

4. To determine whether soil moisture changes significantly with distance from the road and if soil moisture approaches the permanent wilting point.

The purposes of this thesis are (1) to show the development of an experimental design, (2) to describe the design and installation of equipment to accomplish the study objectives, and (3) to examine enough data to estimate the efficiency of the experimental design and installation.

Measurements were made of soil moisture, subsurface seepage from the road cutbank, hydraulic conductivity, ground water levels and precipitation. Partial results show that the depth to bedrock and other associated variables have a profound effect on soil moisture. Measurements of subsurface seepage from logging road cutbanks during the snowmelt season show that these roads have a great potential for affecting streamflow hydrographs.

# DESIGN AND INSTALLATION OF A STUDY TO DETERMINE THE EFFECT OF MULTIPLE LOGGING ROADS ON THE SOIL MANTLE HYDROLOGY OF A SPRUCE-FIR FOREST

by

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ABSTRACT

The U. S. Forest Service, Intermountain Forest and Range Experiment Station, initiated a study in 1960 of the effect of multiple logging roads on the soil mantle hydrology of a spruce-fir forest. Two types of logging roads, insloped and outsloped, were identified by disposition of drainage water. The study objectives were:

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# CHAPTER I

## INTRODUCTION

Water contained in the high mountain snowpack is one of the most valuable natural resources in the economy of the western United States. Irrigation is one of the prime uses of this water. The Columbia River Basin has 4 million acres of irrigated land, and plans call for future irrigation of twice this acreage within the basin (25)[1/]. The Missouri River Basin has 5 million acres under irrigation with a 50 percent planned increase. The anticipated amount of snowmelt runoff and the time at which it can be expected are also important factors for efficient hydroelectric operations. Sport fishing and other fresh water recreation activities depend largely on a continuing supply of high quality water. Of the average annual flow from these two rivers, 66 percent (27 million acre feet) of the Columbia River and 36 percent (6 million acre feet) of the Missouri River originate on national forest land (25). These lands are also called upon to provide timber products --but not to detrimentally affect the water resource. One of the major challenges in watershed management research is to predict the effect of forest site treatment on the total quantity of streamflow and its seasonal changes.

In 1960, personnel of the Intermountain Forest and Range Experiment Station of the U. S. Forest Service, initiated a soil mantle hydrology study in a north Idaho spruce-fir forest. This study was inspired by the

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[1/] Numbers in parentheses refer to items listed under Literature Cited.

possibility that the construction of logging roads on forest lands may have a hydrologic effect which would increase flood potential and decrease soil moisture. Each year in the northern Rocky Mountain region (northern Idaho, eastern Washington, western Montana and southwestern North Dakota) over 1600 miles of logging roads and spurs are built on national forest lands, an operation that removes protective ground cover from 10,000 acres of forest soil (25). Most of the easily accessible areas have already been logged and new logging areas are being opened up in the higher elevation, high-precipitation forests. Concern that the management of the timber resource will have a pronounced influence on the water resource has forced an answer to the question of the hydrologic effect of logging road construction.

Most logging roads can be classified into two types based on road surface drainage practices: insloping and outsloping. An insloped road allows drainage water to flow into and along an inside ditch to culverts or cross drains at widely spaced, fairly regular, intervals. Outsloped roads usually have a very low gradient and are sometimes referred to as contour roads. Contour roads discharge drainage water onto the road fill rather uniformly or at short random intervals along the road length. The hydrologic effect of insloped roads is to transport and dispose of drainage water at a location remote from the tributary area; this may possibly create a condition where the soil mantle may be drier below than above the road. Conversely, for outsloped roads there should be little difference in soil moisture above and below the road since surface drainage is allowed to run onto the road fill along the length of the entire road.

These effects would be most noticeable in areas of high precipitation although the relative effect may differ for roads built in forested or clearcut areas. Furthermore, the influence of any road may be affected by the position of that road relative to other roads above or below it. Therefore, the objective of this research is to measure the hydrologic effect of multiple logging roads on clearcut and forested areas in a high-elevation spruce-fir forest in northern Idaho.

This thesis describes the design and installation of equipment and instruments needed to efficiently and economically achieve research objectives for this soil mantle hydrology study. Study objectives are:

1. To measure the effect in area-inches of water of insloped and outsloped logging roads on soil moisture content.

2. To determine how the road influence, if any exists, is compounded by the presence of more than one road.

3. To determine in area-inches of water the effect of clearcutting timber on soil moisture on both roaded and unroaded sites.

4. To determine whether soil moisture changes significantly with distance from the road and if soil moisture depletion approaches the wilting point.

The thesis problem has as its objectives, first, to develop an experimental design to fulfill the research study objectives; second, to design and install instruments and equipment necessary to fulfill study objectives; third, to check the efficiency of the study design and installation by a brief examination of some of the field data.

# CHAPTER II

## REVIEW OF LITERATURE

The review of literature presented here is by no means complete, but is sufficiently extensive to include all major phases of the research problem. Given a problem with objectives as broad as outlined in Chapter I, it will be necessary to review results of past studies in plant-precipitation relations, soil-water relations, and techniques for measuring soil moisture and other hydrologic parameters. Therefore, this review is limited to (1) the geographic distribution of spruce-fir forests, (2) methods and relative accuracy of soil moisture measurements, (3) relation of timber cutting to soil moisture, and (4) effect of soil structure on groundwater flow.

### GEOGRAPHIC AND PHYSIOGRAPHIC DISTRIBUTION OF SPRUCE-FIR FORESTS

Engelmann spruce (*Picea engelmanni* Parry) and alpine fir (*Abies lasiocarpa* (Hook.) Nutt.) are the two principal species of this forest type. Geographical distribution of Engelmann spruce and alpine fir (2) is shown in Figure 1. Alpine fir is referred to as "an almost constant companion of Engelmann spruce in the Rocky Mountains;" in fact, the range of alpine fir south of Canada is essentially the same as Engelmann spruce. Elsewhere, alpine fir extends farther north to the Yukon.

The spruce-fir forest type occupies the highest, coldest, and most humid portions of the western United States. Alexander (2) shows habitat conditions for Engelmann spruce for four climatic zones within its geographic range. The study area falls within the northern Rocky Mountain zone and, within this zone, Engelmann spruce ranges from elevations of

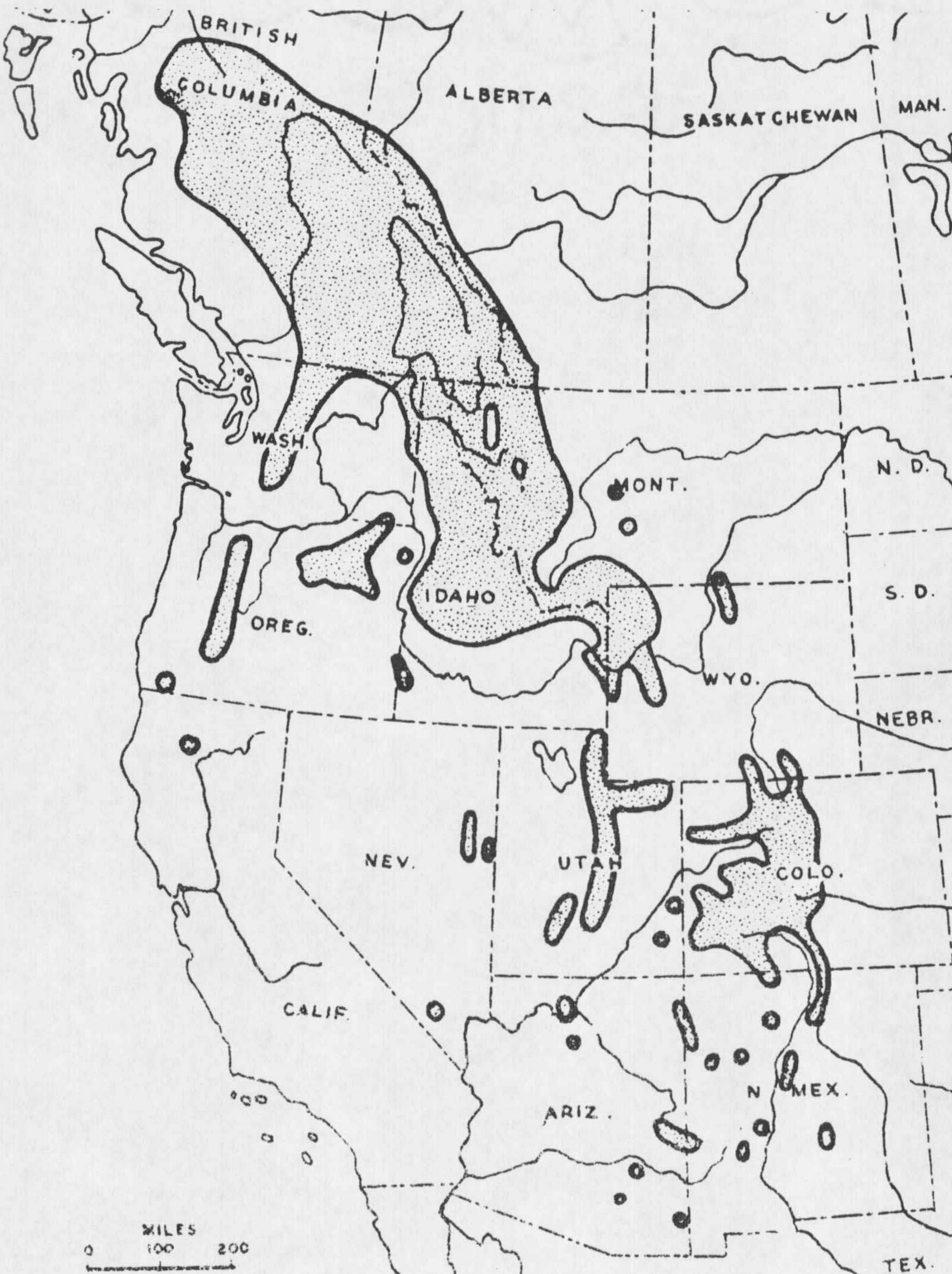


FIGURE 1. Geographic distribution of Engelmann spruce

2,000 to 11,000 feet. The spruce-fir forest type proper begins at about 5,500 feet and ends at about 10,000 feet. Below 5,500 feet, spruce grows with larch, lodgepole pine or Douglas-fir. Above 10,000 feet, alpine fir grows alone or with whitebark pine or alpine larch (2,12).

METHODS AND RELATIVE ACCURACY OF SOIL MOISTURE MEASUREMENTS

Of all hydrologic variables, few are more difficult to measure than soil moisture. The four most common methods are gravimetric, electrical resistance, tensiometer, and neutron scattering.

1. Gravimetric

The gravimetric method consists of collecting, weighing, drying, and reweighing a soil sample to determine its moisture content. Oven-drying for 24 hours at 105°C is the most common procedure; however, some (18) advocate the use of alcohol to heat the soil and eliminate the necessity for oven drying.

For the usual gravimetric method, two authors (21,31) list three serious disadvantages:

1. Much labor is required to secure and process samples.
2. Repeated sampling destroys the experimental area.
3. Single-grained dry soils and stony soils are difficult to sample.

Further, the question has been raised (21) whether soil with free water can ever be sampled accurately by the gravimetric method because of water lost from the sample by drip and by soil compaction.

2. Electrical-resistance

Electrical-resistance methods measure soil moisture *in situ* by relating electrical resistance of electrodes buried in the soil to the soil moisture content. Lull (21) describes the use of such various materials as plaster of paris, fiberglas, fiberglas-gypsum, and nylon blocks to contain the electrodes and allow placement as a unit in the soil. The principal advantage of electrical-resistance is its speed. Lull (21) reports that only 1 minute and 26 seconds were required to make 10 soil moisture readings with fiberglas units. In addition to speed, electrical resistivity measurements are reproducible, and the units (except for those of plaster of paris) remain serviceable for years (31). Disadvantages of electrical resistivity lie principally in calibrating the units, i.e., correlating resistance in ohms with soil moisture content. Considerable disagreement seems to exist as to the best means of calibration--field or laboratory. One author (21) attributes the difficulty to hysteresis effects, which is the tendency of a unit at a given soil moisture tension to register a higher moisture content during soil drying than soil wetting. Carlson (11) recommends field calibration to avoid moisture gradients in laboratory cores and swelling of soil cores.

Another disadvantage is cost; each fiberglas unit costs approximately $7.50. Even with a price reduction for quantity, costs of fiberglas units for an extensive soil moisture study may be prohibitive.

3. Tensiometer

The tensiometer is another important instrument for recording soil moisture content. It consists of a porous ceramic cup in contact with the soil, connected to a vacuum gage or mercury manometer (21). When the system is filled with water and is at equilibrium with soil moisture, any change in soil moisture will either cause water to move into or out of the system thus resulting in a pressure change. This instrument functions from 0 to 0.85 atmosphere equivalent to a soil-moisture range from field capacity to wilting point for fine soils and about 90 percent of this range for coarse soils.

This instrument must also be calibrated, but a laboratory calibration in a large container of soil which can be weighed is sufficient. Hysteresis effects are also noted in tensiometers and, in practice, usually only the drying cycles are used.

4. Neutron-scattering

The newest technique for determining soil moisture content is the neutron-scattering device. This instrument uses a radioactive source to provide high-speed neutrons for moderation by hydrogen atoms contained within the soil water. A counter or ratemeter tallies the returning moderated or low-speed neutrons and, because the number of moderated neutrons is directly proportional to the number of hydrogen atoms in the soil water (30,31,22,32), the neutron meter measures the soil water in all of its phase states (solid, liquid, vapor). The assumption is made that all neutron moderation is accomplished by hydrogen atoms, but this is not strictly true for soils with high concentrations of boron or lithium salts. For soils with this unusual chemical composition special calibration must be made.

Neutron counts can be taken relatively quickly. Field tests by the author with radium-beryllium source equipment show that 200 to 250 1-minute readings may be made in 6½ hours--about 1.56 to 1.95 minutes per reading. Newer instruments with americium-beryllium sources give off more than

3 times as many fast neutrons per unit time than the older radium-beryllium source equipment. This results in a thermal neutron count which is nearly constant for a given soil moisture content so that a ratemeter may be used instead of a 1-minute counting time. Field trials have shown that this newer equipment is much faster than the older instruments.

A significant advantage of the neutron method is the type of sampling inherent in this method. All other methods sample a minimum volume of soil; but the neutron method samples a flattened spherical-shaped soil volume varying from 16 inches in diameter for dry soils to 7 inches in diameter for wet soils. For wet soils the moisture reading averages the water content over a soil volume of almost 0.5 cubic feet.

The neutron method requires a metal access tube to allow entry of the probe into the soil. By moving the probe vertically within the access tube, discontinuities within the soil profile can be picked up. McHenry (22) reports bands of wet or dry soil 1 inch thick can be detected by neutron meters.

Lull (21) warns that neutron scattering equipment frequently breaks down; however, the advent of transistorized equipment with modular construction makes electronic breakdown infrequent and easily repaired. Experience by the author has shown that the most frequent cause of trouble is a mechanical failure of the scaler-to-probe cable connection (7). The use of a simple adapter to hold the cable rigid at the probe connection reduced the frequency of these breakdowns.

Most references (30,31) state that the factory calibration curve is valid for ordinary soils. However, later investigations have shown field calibration to be necessary for some makes of neutron moisture equipment (20).

The greatest disadvantage of the neutron method is the difficulty in installing access tubes in rocky soils with minimum site disturbance. For accurate measurements, access tubes must have the smallest possible air gap between tube and soil. Troxler (29) suggests the dimensions of this air gap not exceed 0.15 inch. If the soil is uniform and relatively rock-free, access tubes can be put down by augering from inside or jetting with water or air (30,1). In stony soils, a drill--either a wagon drill or tractor-mounted--must be used (7,9,27). Depending on technique and/or equipment used, this may result in oversized holes which must then be backfilled to eliminate air gap (31).

Measurement accuracy is an important consideration in the selection of a sampling method. Lull (21) reports neutron moisture readings at least as accurate as electrical-resistivity readings. The Forest Service (31) claims resistance errors to be 0.5 percent by volume for soil moisture below field capacity, and about 1 percent by volume above field capacity. Another reference (30) gives a standard error of 0.5 percent by volume for the soil moisture range of 15 to 35 percent by volume for neutron moisture measurements.

Gravimetric sampling involves two variables, according to the Forest Service (31), percent moisture by weight and soil density and their interaction. Sampling intensity required for a given standard error of moisture by gravimetric and neutron methods showed that one neutron measurement was equivalent to about seven gravimetric samples.

RELATION OF TIMBER CUTTING TO SOIL MOISTURE

It is important to note that exact evapotranspiration rates are difficult to determine and many methods have been developed to estimate evapotranspiration. Many researchers have determined transpiration rates by weighing potted plants, but Kittredge (19) makes the point that "if pots or tanks or lysimeters constitute physiological disturbances for parts of the roots, as they probably do, then the factors obtained from plants so grown and the estimates of transpiration are likely to be seriously high." Wisler and Brater (33) note that transpiration rates determined from potted plants grown outdoors under a wooden shelter may be 20 percent too low. With these considerations in mind, it appears that evapotranspiration rates measured from undisturbed vegetation will give the most reliable estimates.

Numerous authors have noted stream flow increases following timber cutting or burning and have used such observations as estimations of the evapotranspiration draft. One of the earliest papers is by Hoyt and Troxell (14) who reported average annual streamflow increases of 15 percent in Colorado following planned defoliation and a 29 percent increase in California following a fire. Another study (13) involving the removal of forest vegetation from a small watershed in western North Carolina revealed an average evapotranspiration draft of 17 inches annually.

Estimates of evapotranspiration loss can also be made by measuring soil moisture. Bay and Boelter (3) show that evapotranspiration draft is definitely related to vegetation density. Soil moisture depletion under red pine stands in northern Minnesota showed depletion was greatest under the most dense stand with the 3-year average annual soil moisture deficit as follows:

| Square feet of basal area | Soil moisture deficit (inches) |
|---|---|
| 140 | 5.9 |
| 100 | 5.2 |
| 60 | 4.1 |

The majority of red pine roots were found in the upper 3 feet of the soil profile, and 60 percent of the soil moisture deficit occurred within this zone.

EFFECT OF SOIL STRUCTURE ON GROUNDWATER FLOW

There is evidence that the structure of the soil profile can cause "subsurface storm-flow" (15). Hursh and Brater (16) recognized this phenomenon and refer to it as "storm-augmented" groundwater. Hursh and Hoover (17) have shown that up to 15 percent of the total precipitation is transmitted laterally downslope in the first 12 inches of the soil profile. This soil characteristic suggests a large water-moving potential for forest soils when the profile is saturated, as at the time of spring snowmelt. The construction of many miles of logging road could theoretically alter stream hydrographs into an undesirable, flashy configuration by collecting seepage and conducting it immediately to a stream channel.

The literature search failed to locate any reference to prior studies which delineated the amount of soil moisture lost from a site by logging roads.

# CHAPTER III

# METHODS

With the research objectives defined, the next problem that arises is the selection of a study area and the development of an efficient experimental design. This section outlines the criteria used to select the study area and the principles observed in the development of the experimental design.

## GENERAL DESCRIPTION OF THE STUDY AREA

Criteria used in selecting the study area were (a) a mature spruce-fir forest, and (b) a north aspect-high elevation site for maximum precipitation opportunity. Several prospective sites with roads already built through forested and clearcut blocks were examined and rejected because of varying road spacing, changing aspect over the site, or unroaded forested and clearcut control areas too remote from the site. It became apparent by the fall of 1960 that the best chance for finding a good study area would be to locate a potential study area near an active logging area and require that the logging contractor build the roads and cut the timber on the site to fit research requirements.

A 24-acre study area was located in December 1960 at the headwaters of the Lochsa River in Idaho (Figure 2). The study area has a gently concave configuration with aspects which range from N15°E to N13°W. The area lies midway between ridge and valley and has a mean elevation of 6400 feet. Slope gradient increases from 20 percent at the upper boundary to 27 percent at the lower edge. Vegetation on the study area is typically old growth spruce-fir timber with a tree canopy composed of Engelmann