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
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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: 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

EDWARD ROBBINS BURROUGHS, JR.

A thesis submitted to the graduate faculty in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Civil Engineering

Approved:

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MONTANA STATE UNIVERSITY
Bozeman, Montana

June, 1967
ACKNOWLEDGEMENTS

The author wishes to thank the U. S. Forest Service, Intermountain Forest and Range Experiment Station for the opportunity to use the "Logging Road" study as the basis for this thesis. In particular, thanks go to Mr. Paul E. Packer, Project Leader, Forestry Sciences Laboratory, Logan, Utah, for the original idea and subsequent support. Thanks are also given to Mr. Harold F. Haupt, Project Leader, Forestry Sciences Laboratory, Moscow, Idaho, and Dr. Otis L. Copeland, Jr., Assistant Director in charge of Forest Fire and Watershed Management Research, Ogden, Utah, for their careful reviews of the manuscript.

Thanks are also extended to the faculty of the Civil Engineering and Engineering Mechanics department of Montana State University for their assistance, and especially to Professor T. T. Williams for his patience and guidance in preparing this thesis.

Finally, thanks go to my wife, Virginia, for her help and encouragement.
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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:

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.
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). 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

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 engelmannii 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 I. 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, fiberglass, fiberglass-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 fiberglass 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 fiberglass unit costs approximately $7.50. Even with a price reduction for quantity, costs of fiberglass 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.
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:

<table>
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<th>Square feet of basal area</th>
<th>Soil moisture deficit (inches)</th>
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<tr>
<td>140</td>
<td>5.9</td>
</tr>
<tr>
<td>100</td>
<td>5.2</td>
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<tr>
<td>60</td>
<td>4.1</td>
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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 theoreti-
cally 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
FIGURE 2. Area map showing location of study area
spruce, alpine fir, and a few whitebark pine. The understory is layered with a tall (5 to 7 feet) brush (Menziesia), a low (1 to 3 feet) brush (Vaccinium) and a ground cover of forbs, mosses and lichens (Figure 3). The timber stand composition based upon a 20 percent sample of the study area is shown in Table I.

Table I. TIMBER STAND COMPOSITION BASED ON A 20-PERCENT CRUISE OF THREE 4-ACRE BLOCKS

<table>
<thead>
<tr>
<th>Block</th>
<th>Spruce</th>
<th>Fir</th>
<th>Spruce Bd. ft</th>
<th>Fir Bd. ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 2</td>
<td>31</td>
<td>32</td>
<td>3,395</td>
<td>902</td>
</tr>
<tr>
<td>Block 5</td>
<td>19</td>
<td>53</td>
<td>1,268</td>
<td>1,859</td>
</tr>
<tr>
<td>Block 6</td>
<td>15</td>
<td>37</td>
<td>1,332</td>
<td>1,222</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5,995</td>
<td>3,983</td>
</tr>
<tr>
<td>Total merchantable board feet</td>
<td></td>
<td></td>
<td>29,975</td>
<td>19,915</td>
</tr>
<tr>
<td>Merchantable board feet per acre</td>
<td></td>
<td></td>
<td>2,725</td>
<td>1,610</td>
</tr>
</tbody>
</table>

The region, including the study area, lies sufficiently far east of the Coast Range to have an intermountain type of precipitation pattern—cold, wet winters and hot, dry summers. At 6,400 feet, winter precipitation averages about 30 inches of water in a snowpack which begins to accumulate in October and reaches a maximum depth of 6 to 8 feet in March. Late winter snows and spring rains add more water until by the time the snowpack has melted (about the first of June) the entire soil profile is saturated and overland flow occurs over most of the area. Only scattered
intense thunder showers provide moisture from July to September when a short rainy period is followed by snow. Total annual precipitation ranges from 40 to 45 inches.

The study area lies along the eastern margin of the Idaho batholith where the native rock is representative of the border zone schists and gneisses as well as massive igneous material of the batholith proper. Both the metamorphic and the igneous rock types exist as gruss, a fragmental granular material that occurs in the transition of granitic rock from solid state to soil. A portion of the soil mantle was transported into the area by glacial ice and deposited as debris. The gruss has a particle size range of coarse to medium sand, while the glacial material ranges in size from silt to large rock. The rocks lie at random orientation and depth. (Figure 4).

EXPERIMENTAL DESIGN

The research objectives necessitate a unique study; therefore, it was apparent that careful planning would be necessary to design such a study. It would also be necessary to modify those plans which were found to be inefficient or impractical during installation. This section on experimental design is presented in such a way as to describe in detail the experimental design and the considerations that led to the design.

1. Road Treatment

The average center-to-center slope distances between roads in logging operations may vary from a minimum of 60 feet to nearly 300 feet.

Extracted from a report of a seismic investigation of the study area by B. L. Hicks of the Minerals Management Branch, U. S. Forest Service, Missoula, Montana.
FIGURE 3. Undisturbed vegetation on a forested block

FIGURE 4. Soil under an overturned Engelmann spruce
This road spacing is a function of the type of log loader used and amount of cable carried on the winch drum. Truck-mounted log loaders are in common use today and the average slope distance between road centers is about 200 feet. Road width depends on the amount of expected traffic and the size of the equipment using the road. The logging contractor will build the minimum road width necessary to handle his equipment and thereby reduce his logging costs. In practice, these roads will vary from 12 to 18 feet from the bottom of the road, cut across the road crown to the fill shoulder; an average road width would be about 14 feet. Roads on the study area were built 14 feet wide and 200 feet apart, center to center, slope distance.

The upper road of a series of insloped roads could collect overland flow and ground water from a tributary area which may be quite large relative to the tributary area between the upper road and the second road. Theoretically, the area below the upper road may not be saturated because the upper road will have intercepted overland flow and some groundwater flow. Three roads were used to demonstrate the road effect without creating such an extensive network that it would be impossible to install the required amount of experimental facilities.

The basic feature of insloped roads is the presence of the inside ditch which carries all drainage water to selected disposal points at widely spaced intervals. To simulate this on the study area, each insloped road had a gradient of 2 to 4 percent with an inside ditch to carry drainage water to an installation to collect drainage water from all insloped roads and conduct it entirely away from the study area. Outsloped
roads were built on a level gradient with the road surface given a slight pitch to the outside.

2. Timber Cutting

Logging roads in the northern Rocky Mountain region may traverse large areas of uncut timber to reach the logging area so that each of the two basic road types will be found in both clearcut and forested areas. The same road type built through a clearcut and a forested area may behave quite differently hydrologically because of the greater evapotranspiration draft on soil moisture within the forested area. Therefore, each road type on the study area was built through a clearcut and a forested block to determine the effect of two road types and two vegetation conditions on soil moisture. Two unroaded blocks, one clearcut and one forested, were established as controls from which to estimate the evapotranspiration draft of spruce-fir timber. The six blocks are described as follows: insloped-forested, insloped-clearcut, outsloped-forested, outsloped-clearcut, unroaded forested and unroaded clearcut (Figure 5).

3. Subdivisions of Blocks

Each block was subdivided into smaller units to allow comparison of the effect of any road with that of an adjacent road. Each road forms the center line of a subblock 200 feet long and 200 feet wide. The subblocks can be compared with each other and, within each subblock, soil moisture above the road can be compared with soil moisture below the road. Soil moisture measurements within a clearcut block may be confounded by transpiration draft from tree roots extending from an adjoining forested
FIGURE 5. Block layout within the study area
block. The areal extent of tree roots for all species is not known; however, lodgepole pine (6), ponderosa pine and Douglas-fir (4) roots have been measured a maximum horizontal distance of 21 feet from the stem. These measurements were made on small trees 20 to 40 feet high, whereas the trees in this study area are of different species and average nearly 100 feet in height. Each block has a buffer zone 50 feet wide inside its boundary to create a central measurement zone. A 100-foot buffer zone was used at the top and bottom of each block; this made each block 200 feet wide and 800 feet long.

A balanced experimental design required subblocks to be located in the same manner for unroaded as for roaded areas. This was accomplished by establishing three imaginary roads on the unroaded blocks. Once the line of the imaginary road cuts and shoulders was located, subblock boundaries were staked out on the unroaded blocks.

4. Selection of Total Number and Location of Soil Moisture Access Tubes

To accurately describe time trends, soil moisture should be remeasured as often as possible, especially during spring and fall when it changes most rapidly (5). The total average time between snowmelt and snow accumulation on the study area is 105 days (June 10 to September 25). If 15 measurements were used to describe seasonal soil moisture trends this would make an average measurement cycle of 7 days.

Soil moisture should be sampled to a depth equal to the road cut height or to the maximum depth of tree root penetration, whichever is greatest. Since spruce trees have a characteristic shallow-spreading root system (overturned spruce show a vertical root penetration not exceeding
5 feet) and heights of road cuts on the area seldom exceed 3 feet, soil moisture was sampled each foot to a depth of 5 feet.

Two Troxler neutron soil moisture meters with radium-beryllium sources were available for this study. A 1-minute counting time with this type of equipment gives an average random error of 0.11 inch of water per foot of soil containing 25 to 50 percent moisture by volume and 0.07 inch of water per foot of soil containing 0 to 25 percent moisture by volume (23). The use of a 1-minute counting time per measurement requires about 9 minutes to take five 1-minute measurements at each location, then travel to the next location. When travel time and setup time were deducted from the standard 8-hour day, there were only 6 effective work hours per day on the area. Each 7-day measurement cycle had 5 work days, but because some equipment breakdown or adjustment was expected a 4½-day work week was used.

On the basis of 9 minutes per location for 6 hours per day per 4½-day week, 180 locations could be measured every cycle by each field crew, for a total of 360 locations per cycle. This was divided into 60 locations per block, 20 per subblock, or 10 locations above and 10 locations below each road. The locations above the road began at the bottom of the road cut bank and proceeded upslope to the top of the subblock boundary; those locations below the road began at the road shoulder. Soil moisture was expected to change most rapidly nearest the road cut and road fill, therefore sampling was most intense nearest the road and progressively less so toward the subblock boundaries. Beginning at the bottom of each road cut, one point was located at 0, 2.5, 5.0, 7.5, 10, 15, 25, 40, 60, and 80 feet
upslope, and beginning at the top of the road fill one point was located at 0, 2.5, 5.0, 7.5, 10, 15, 25, 40, 60, and 80 feet downslope.

Knowing the distance of each soil moisture measuring point from the road, there are two ways to select the distance for each measurement point from the side of the subblock. First, a random distance from the subblock boundary can be chosen and a line transect run through this point perpendicular to the road. All measurement points would be located on this transect line. Second, each measurement point would have its distance from the subblock boundary randomly selected. If there were a zone of aberrant soil extending down through the subblock, it would be possible with the first method to have all measurement points located in this zone and thus sample conditions not found anywhere else on the area. The second method was chosen because this method samples the entire area randomly and reduced the chance of many samples in any subblock falling within an aberrant zone. The distance in feet of each soil moisture measurement point from the east boundary of the measurement zone was randomly selected from consecutive numbers 0 to 100 (see Figure 6). A list of 10 alternate numbers was drawn up for each subblock in the event a point fell on a site where it was impossible to establish that point.

5. Measurement of Seepage Flow

Groundwater seepage from road cutbanks, like soil moisture, will also be affected by timber cutting. Cutbank seepage should be greater from clearcut than from forested areas because of the reduced transpiration draft on soil water within a clearcut. To satisfy research objectives soil moisture data were supplemented by cutbank seepage measurements.
FIGURE 6 Access tube location within subblocks
One of the difficulties in measuring cutbank seepage is the separation of cutbank seepage from snowmelt and/or precipitation flowing off the area above the road as overland flow. A "V"-shaped installation was developed to be installed on the slope above the road cut to divert overland flow to each side of the measurement zone and discharge it over the road cutbank.

Seepage flow from the road cutbank must be collected, kept separated from road surface drainage, and conducted to a point where it can be measured. This was a problem only on insloped roads where there must also be an inside ditch. Collected seepage was conducted to a measurement device that made a continuous record of this seepage flow. The seepage measurement device built for this study consists of a stilling basin, a Parshall flume connected to a stilling well, and a water level recorder to measure water level in the well (8). Nine weight-driven, clock-regulated, roll-chart water level recorders loaned by the U. S. Geological Survey and four clock-driven, strip-chart water level recorders from another project were used to record seepage flow data.

Outsloped roads were provided with an installation to redistribute measured seepage flow uniformly along the road fill within the measurement zone so as not to deprive the area below the road of seepage water that would naturally go there (Figure 7).

6. Measurements of Hydraulic Conductivity and Groundwater level

Measurement of hydraulic conductivity is important for two reasons; first, measurement of this parameter provides an estimate of the uniformity
FIGURE 7. Diagram of systems for measuring cutbank seepage from insloped and outsloped roads.
of the soil throughout the area; second, knowledge of variations in hydraulic conductivity from block to block may be used in model studies to adjust field data to uniform conditions.

Measuring hydraulic conductivity in the field is preferable to laboratory measurements because laboratory determinations are subject to errors caused by soil sample disturbance. A number of field methods for measuring hydraulic conductivity are to be found in the literature. Although many methods use the rate of rise of water in a pumped well to develop hydraulic conductivity for a site, Hooghoudt's method (26) was used for this study because it appeared to be the simplest and the most accurate. One hundred eighty wells were drilled adjacent to the 5, 15, 25, 40, and 60-foot access tube locations within each subblock. Each well was drilled 36 inches from the appropriate access tube, at approximately the same ground elevation. Each hole was drilled 6 feet deep, a 3/4-inch galvanized iron pipe inserted, and the annular space filled with fine gravel to support the sides of the hole. The well was pumped dry and the rate of rise measured through the central pipe. The wells were thereafter available as permanent water level observation wells.

7. Precipitation Measurement

Precipitation was measured at two locations: one on a forested, and one on a clearcut block to provide a variable for statistical analysis of field data, as background information for the study area, and as a measure of the spruce-fir forest canopy interception. Cumulative winter precipitation was measured during the period between field seasons by 2 snow storage gages. Summer precipitation measurements include all precipitation
occurring during the field season; this was measured by two weighing-type recording raingages. The station in the clearcut was located as far as possible from the surrounding timber to avoid any interception effect (Figure 5 and Figure 8). The forest canopy on the study area is not a closed canopy but has many small openings, therefore, the precipitation measurement location within forested areas represents an average site and has some canopy openings within its sphere of influence (Figure 3 and Figure 9).

8. Soil Samples

Soil samples were collected and at some future date certain soil characteristics will be measured to: (1) determine the degree of soil uniformity throughout the study area, and (2) establish the permanent plant wilting point to measure the degree of soil moisture depletion. Soil moisture at various points was measured with the neutron meter while the soil was completely saturated to yield a measure of the total soil porosity. Soil saturation was indicated by water on the surface or just below the surface as measured in the observation wells. A mechanical analysis of soil samples taken from the study area will be taken as a measure of soil homogeneity. Permanent plant wilting point is of interest because soil moisture on the road cut or road fill may approach this point during midsummer and may account for slow forest regeneration on these areas.

Soil samples were taken from pits dug in the buffer zones beside each subblock to avoid soil disturbance within the measurement zone.
FIGURE 8. Clearcut precipitation gage, May, 1966

FIGURE 9. Forested precipitation gage, May, 1966
CHAPTER IV

INSTALLATION OF EQUIPMENT

Installation of instruments and equipment occupied the summers of 1961, 1962, and part of 1963. Installation of each of the main items of equipment will be described in sufficient detail to illustrate the procedure. The installation schedule is shown in Table II.

INSTALLATION OF ACCESS TUBES

When the field season opened about the middle of June 1961, the logging contractor finished cutting timber in the corners of the clearcut areas, piled slash and snags in windrows along the buffer zones, and straightened up the logging roads as he left the area. This work required two weeks, and during this period when no field work could be done, soil moisture access tubes were prepared for installation.

The manufacturer of the neutron moisture meters used in this study (Troxler Electronics Laboratories, Inc.) recommends 6063-T6 aluminum tubing 2 inches O.D. and 0.05-inch wall thickness to be used for access tubes. A minimum access tube length of 5 feet 10 inches below ground was required for soil moisture measurement 5 feet deep. Access tubes as installed were 7 feet 6 inches long over-all and were installed 6 feet into the ground; this left 18 inches above ground. Each tube was sealed by a rubber stopper cemented into the lower end of the tube with a rubber-base cement. After this cement had set, the outside of the stopper was covered with cement to seal the joint.
### Table II. Installation and Measurement Schedule

<table>
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<th>August</th>
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<td>Drainage flume</td>
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<td>Sacramento snow gages</td>
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<td>Seepage collectors</td>
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<td>Overland flow diversions</td>
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<td>Redistribution systems</td>
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<tr>
<td>Hydraulic conductivity wells</td>
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<td></td>
</tr>
<tr>
<td>Rebuild drainage flume</td>
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<td></td>
</tr>
</tbody>
</table>

1961

1962

1963

Weighing recording raingages
Soil moisture measurements
Seismic survey
Soil samples
Subblocks and measurement zones were laid out in each block and each access tube location was randomly established as outlined in Chapter III, Section 4. A steel rod 3/8 inch in diameter and four feet long with the upper half dipped in highly visible yellow traffic paint was driven into the ground at each tube location. Each rod had an aluminum tag with the tube number, subblock number and distance above or below the road stamped thereon.

Initially, holes for access tubes were drilled by 2 two-man crews using a pneumatic hammer and compressor. This method worked well in Utah where a two-man crew could install six 8-foot access tubes per 8-hour day. Soils on the Utah sites are residual, with a soil profile relatively free of boulders and cobbles. Soil conditions on the logging road study are much more difficult for tube installation because of the many large rocks throughout the soil profile. For rocky soils such as this, the hand-held pneumatic drill is not practical because of two problems caused by the small drill shank and the relatively large drill bit (7, 9, 27). First, when a sloping rock surface is encountered, the drill bit will drift downslope until the drill shank reaches the side of the hole and prevents further deflection. With two or three such rocks in any one hole, the resulting access hole will be extremely crooked and will require much backfilling to prevent large voids around the tubes. The second difficulty is caused by the small central hole in the drill shaft which conducts air from the supply line to the drill bit to keep rock cuttings from jamming the bit. Insufficient air volume will let cuttings and soil accumulate behind the bit, then drilling must stop until the drill can be
hauling to the surface and the hole blown clean with a separate blow-pipe. This laborious process yielded only four 6-foot holes per day, just half the drilling rate on the Utah study area.

To improve drilling efficiency a D-2 crawler tractor with a hydraulic-controlled dozer blade was used to lift the drill from the ground when the bit became stuck. This innovation doubled production but the resulting holes were still crooked and required considerable backfilling around the tubes. Much experimentation with procedure and equipment was made, but in spite of delays all 360 access tubes were installed the first field season.

**INSTALLATION OF THE DRAINAGE FLUME**

The drainage flume generally follows the boundary between Blocks 2 and 3 beginning at the upper road and ending 120 feet below the lower road. Its location was staked out and slope distances and gradients were measured between stakes. The flume had its lowest gradient (1\% percent) where it passed under each road. The equipment operator used a D-4 crawler tractor to open up each road crossing about 3 feet deep at the cut side and about 5 feet deep on the fill side, then graded the remainder of the flume location between road crossings.

Two sizes of trapezoidal flumes were designed to accommodate the increased volume of flow below the second and third roads. A snap-on metal lid was fashioned for each 4-foot galvanized iron flume section. The lid served to hold the flume width constant and keep extraneous water and trash from entering the flume.
At each road crossing a 12x12-inch wooden box 16 feet long was built around the flume to prevent earth pressure from crushing the flume, and the complete installation laid in the crossing with a top 2 feet below grade. Where the flume intersected the inside ditch a simple wooden drop inlet was constructed. The road crossings were then filled in and compacted (Figure 10). Between road crossings the flume sections were overlapped 1 inch, the joints sealed with asphalt mastic and the sections joined with sheet metal screws. The flume installation was completed in the fall of 1961.

When the area became accessible in the spring of 1962, it was found that the heavy snowpack had flattened many lengths of flume. These sections were replaced and lengths of green lodgepole pine 4 to 6 inches in diameter were laid alongside the flume with crosspoles over the flume every 4 feet. Smaller poles were then nailed to these crosspoles to form a framework to carry the snow load (Figure 10). At this time, a rock-filled log crib was built onto the terminal end of the drainage flume to reduce the kinetic energy of the flume discharge. A trough was built across the bottom of the crib to collect drainage water and carry it to the nearest wooded area for disposal. Examination of the flume in the spring of 1963 showed no damage to the flume and all drainage water at the flume terminus was disposed of in the forest with no erosion damage (Figure 11).

**INSTALLATION OF EQUIPMENT FOR THE MEASUREMENT AND REDISTRIBUTION OF SEEPAGE FLOW**

Each installation for measuring seepage flow consists of three parts: an overland flow diversion, a seepage collection gutter, and a Parshall
FIGURE 10. Typical drainage flume - road intersection

FIGURE 11. Terminus of drainage flume
flume. A fourth part, a seepage flow redistribution system, is needed for outsloped roads (see Figure 7).

The peak of the inverted "V" of the overland flow diversion was located above the road in the center of the measurement zone and string lines were stretched from this peak to the road cut outside of the measurement zone of each subblock. The ground along the string line was opened with axes and overlapping 18-gage galvanized sheet metal pieces 8 x 48 inches were pushed 4 inches into the ground, joined with sheet metal screws and nailed to wooden stakes spaced every 2 feet. The first rain after installation proved the effectiveness of this overland flow barrier (Figure 12).

Installation of seepage flow collectors for each subblock was started by smoothing the ground surface at the bottom of the road cut within the measurement zone. The collectors were made by bending 16x48-inch galvanized sheets into an "L" shape 5 1/2 x 10 inches, with a 3/4-inch flange on the short leg; the 10-inch leg formed the floor of the collector. The sections were overlapped about 1 inch, pressed into the road cutbank, sealed with asphalt mastic and joined by sheet metal screws. Each section was supported along the short leg by nailing through the short flange into wooden stakes driven into the soil (Figure 13). In the case of insloped roaded subblocks, a ditch for road drainage was excavated adjacent to the collector and the loose soil was banked against the collector to complete installation (Figures 14 and 15).

Seepage flow is measured through a Parshall flume connected to a water level recorder to give a continuous record of flow. Two sizes of
FIGURE 12. Overland flow barrier

FIGURE 13. Seepage flow collector
FIGURE 14. Insloped road section

FIGURE 15. Outsloped road section
Parshall flumes—one- and two-inch throat width—were constructed of galvanized metal from specifications given by Robinson (28). All cut-bank seepage in the collector empties into an 8x10x48-inch open-topped galvanized metal stilling basin and from thence flows through the Parshall flume. The Parshall flume and attached 12-inch diameter corrugated metal stilling well are supported atop a concrete foundation. A plywood deck over the Parshall flume supports the water level recorder (Figure 16).

As seepage flow diminished during the summer, the flow eventually became too small to be measured by the flume, as such. When the head on the flume reached 1 inch, a piece of sheet aluminum with a small drilled hole was sealed into the flume throat thus converting the flume to an orifice measuring device. An 8x8-inch piece of aluminum window screen pushed into the converging section of the flume prevents submerged debris from clogging the orifice (Figure 17). Wooden covers for the stilling well and clock-well and a metal cover for the recorder protect the installation from rain and snow. The recorder can be left in place over winter provided logs are laid alongside the installation to bear the weight of snow. The installation is easily made ready for early spring seepage flow measurements (Figure 18).

A redistribution system was installed on all outsloped roads. This installation consists of lengths of 4-inch galvanized iron roof gutter laid on a level grade parallel to the road shoulder. Generally, this trough rests on the ground, but is supported in low spots by timbers. Holes were punched in the sides every few inches to allow water to...
FIGURE 16. Parshall flume installation

FIGURE 17. Parshall flume with orifice insert and debris screen
FIGURE 18. Snowmelt seepage flow measurement. May, 1965
percolate uniformly onto the road fill. This trough is supplied by a 2x4-inch galvanized metal downspout which conveys seepage water under the road surface from the Parshall flume to the trough.

INSTALLATION OF HYDRAULIC CONDUCTIVITY AND GROUNDWATER LEVEL WELLS

The study design called for 180 observation wells 2 inches in diameter and 6 feet deep. To drill this many holes by the same method used for access tube installation would have required 1½ months. Obviously a better drilling method had to be found. Bland Z. Richardson (who is now on the staff of the Intermountain Station but was a student assistant during the summers of 1961, 1962, and 1963) investigated the possibility of using tractor-mounted drilling equipment of the type used for road construction. A D-8 crawler tractor with hydraulic operated drilling equipment mounted on the front and a 350-cfm compressor mounted on the rear frame was obtained for this job (Figure 19). In seven 8-hour days, all 180 holes were drilled with this equipment. The holes were smooth and straight regardless of the amount of rock in the profile. The reasons for the better quality drilling job were: (1) a large diameter drill shaft prevented deflection of the drill bit, (2) the larger air supply removed cuttings from around the drill bit, and (3) air motors provided power to force the bit down into the soil and also removed the bit from the hole when the required depth was reached.

Galvanized, 3/4-inch steel pipes about 7 feet long and perforated by 16 1/4-inch holes located four at each foot beginning 1 foot from the bottom were used for access to the well. When each well had been drilled, a pipe was inserted to 5 feet and the annular space filled with 3/8-inch crushed rock to support the sides of the well. After the field season
opened in 1963, a portable pump was used to flush loose soil out of the well and to assure that the gravel lining was clean.

**INSTALLATION OF PRECIPITATION GAGES**

Two snow storage gages were installed during the fall of 1961. Each leg of the 15 foot high tower was bolted to an angle iron buried in a concrete pier. An 8-inch diameter, 30-inch deep collector can was mounted on the tower within a wind deflector. A gallon of Prestone was added to the empty can to prepare for the first winter's precipitation measurements. When the 1962 field season began, the collector cans were found to be full to overflowing. New cans were built with the same diameter but 5½ inches long, and placed on a lower support to keep the top of the can at the original height. Each can was painted black to absorb more solar radiation and help prevent snow bridging. For each succeeding winter's measurements, two gallons of Prestone were added to each collector can.

**SEISMIC SURVEY**

Near the center of Block 3 is a swampy area caused probably by a rise in the bedrock surface, either at the swamp site or immediately below it, that would force water to the ground surface. To attempt to analyze soil moisture or seepage flow data without some explanation for the increased soil moisture in this subblock would decrease the value of the research results. In the fall of 1963, a seismic survey was conducted on the study area to plot the bedrock surface under the entire area (Figure 20). This survey was completed in two weeks and the results were summarized in January 1964.

The seismic survey showed that bedrock depth decreased steadily from a depth of about 33 feet at the upper block boundary to a 20-foot depth at
FIGURE 19. Tractor-mounted drill

FIGURE 20. Seismic survey
the lower edge of the swamp. Several other minor wet areas in other blocks showed the same correlation between saturated soil and shallow bedrock depth.

Bedrock depths for areas between seismic traverses were interpolated linearly to give a bedrock depth for each soil moisture tube and these data were used as an independent variable in preliminary statistical analyses of 1963 and 1964 field data.
CHAPTER V
MEASUREMENTS

Four parameters were measured on the study area during the 1963 and 1964 field seasons: soil moisture, seepage flow, hydraulic conductivity (1963 only) and depth to water table (1963 only). This chapter describes the measurement procedure for each parameter.

SOIL MOISTURE

Each measurement is representative of the number of neutrons moderated per unit time by water in the soil. To relate the number of counts per minute to soil moisture content, each measurement must be expressed as a percentage of the number of counts per minute with the probe in a "standard" container made of a material with a large hydrogen atom content. The use of this ratio automatically corrects soil moisture readings for atmospheric moisture, temperature and other variables that could affect readings. Each ratio of the soil moisture count to the standard count is converted to soil moisture content (percent by volume) by a calibration curve furnished with each meter. Standard counts were taken frequently during the working day for greater measurement accuracy.

Each series of measurements were preceded by enough standard counts to warm up the scaler circuitry. When the 1-minute standard counts began to show little variation, five counts were recorded on a sheet with the date, time and unit number. Each crew then began taking soil moisture readings where they stopped on their last working day. At noon, each crew took another series of 5 standard counts and entered the counts and the supplementary information on the standard count sheet. The afternoon work
period also began and ended with a series of 5 standard counts. Soil moisture readings taken during a work period are thus bracketed by standard count readings. Soil moisture around an access tube was measured as follows: The first crew member removed the tube cover, set the probe and shield on top of the tube, lowered the probe to the proper depth and started the timber. When the timer stopped, the first crew member read the accumulated counts from the 5-tube counter while the second member of the team recorded the date, the count, and double-checked the counter. After the probe was lowered to the second foot the counter was reset to zero and the timer was started. When the fifth depth was read, the time of day and the unit number were recorded with the count while the probe was withdrawn and the tube recapped (see Appendix A for sample field data sheets). Five depths were measured in a tube and the equipment carried to the next tube in an average time of 7 minutes.

When the 1963 field season opened, the equipment broke down frequently because the electrical cables connecting probe and scaler separated after repeated flexing. One instrument was withdrawn from service so that an effective solution to this problem might be worked out. Bland Z. Richardson developed a cable connection that consisted of a short piece of conduit and a helical spring. One end of the conduit was threaded onto the probe and the other end clamped to the cable tightly with a compression nut, thereby providing slack in the cable at the probe connection. The helical spring, which was silver-soldered to the compression unit, prevented sharp bends in the cable. Each meter averaged only 200 readings between cable failures before this adaption was developed and more than 5,000 readings before another cable breakdown after this adaption was installed.
SEEPAGE FLOW

Each seepage flow installation was protected from the weight of the overlying snowpack by large logs leaning against the cut bank on both sides of the installation. In the spring, these logs were removed, the recorder clocks started, sediment cleared out of the Parshall flume, and the recorder pen set at the correct water depth. Frequent checks were made to see that no sediment blocked the tube connecting flume and well and that the correct water depth was recorded on the chart.

Each Parshall flume was calibrated by measuring the volume of flow over a time interval for a given stage. Calibration was begun in the spring with high discharge and continued throughout the summer to develop a stage-discharge relation for a wide range in stage. When the discharge in any flume became very low, the flume was converted to an orifice type measuring device by the insertion of an aluminum orifice plate in the flume throat. Each station was then recalibrated with the orifice plate sealed in place.

Four seepage flow stations were started about the first of May, 1964 to measure cut bank seepage very early in the year when snowmelt was at its peak. The remaining 8 stations were activated about the middle of June.

HYDRAULIC CONDUCTIVITY

Other observers found Hooghoudt's method for measuring hydraulic conductivity to be accurate to within 10 to 20 percent of true hydraulic conductivity in homogenous soils (26). To gain this accuracy, it is necessary that the rate of rise of water in a pumped well be measured before 25 percent of the volume of pumped water has flowed back into
the well. The need for this is to avoid error introduced by the expanding drawdown cone. Therefore, rate of rise readings must begin as soon as the well is pumped dry.

The pump-manometer developed for this job consists of a 3/4-inch O.D. steel tube screened on the bottom and enclosing a manometer loop made of 1/4-inch copper tubing. The manometer opens at the side of the large tube near the bottom and the upper end passes through a "T" at the upper end of the large tube and is attached to a scale against which the rise of the manometer liquid can be timed (Figure 21). This device is placed into a well, a pump is attached to the "T", and the well is pumped dry. By watching the manometer level drop, the operator can tell when to cut off the pump and begin to time the rate of water rise (Figure 22).

Rate-of-rise readings were made for 1/2-inch increments of rise wherever possible. Alternate increments were measured to allow the operator to read the stopwatch and prepare for the next incremental measurements (Figure 23).

**GROUNDWATER LEVEL**

An 8-foot length of 1/4-inch galvanized pipe was calibrated in inches from the bottom and an "S"-shaped loop of plastic tubing was sealed into the upper end. When a small amount of dyed alcohol is poured into the plastic tubing, the pipe indicates the depth to water by a movement of the alcohol when water is encountered (Figure 24). Depth to the water table from the top of the well pipe was read to the closest inch and estimated to the nearest 1/4 inch. The distance from the top of the well pipe to the ground was subtracted to give depth to water table relative to the ground surface.
Scale can be shifted vertically to align the scale zero with the liquid level

Translucent plastic tubing

Valve

To pump

Conduit

Manometer tubes of 1/8 inch copper

Manometer inlet

FIGURE 21. Schematic diagram of the pump-manometer
FIGURE 22. Pumping the groundwater well

FIGURE 23. Timing water rise in the well
FIGURE 24. Groundwater depth indicator

Translucent plastic tubing

Conduit
CHAPTER VI

PARTIAL RESULTS

The complete analysis of soil moisture and subsurface seepage data taken from 1963 through 1966 is beyond the scope of this thesis. However, enough of the data were analyzed and are presented here to demonstrate the effectiveness of the study design and installation.

SOIL MOISTURE

Field data for the 1963 season were used to develop a statistical model for predicting soil moisture using precipitation, bedrock characteristics and other variables that reference the particular access tube to roads. The 1964 data will be reserved for evaluation of treatment effects using the statistical model developed with the 1963 data.

Development of the statistical model required many trials to establish reasonable expressions to describe the effect of precipitation, bedrock, roads and downslope distance on soil moisture. This process required close collaboration with Michael A. Marsden, Laboratory Statistician for the Forestry Sciences Laboratory, Moscow, Idaho. The equation given below is used to predict the total amount of soil moisture in percent by volume for the first 3 feet. The equation is followed by a definition of the individual and grouped terms (Figure 25).

\[
y = 165.67 + [101.97 \frac{MBD}{LBD} + 398.02 \frac{LBD-MBD}{D_1} + 0.45996D - 0.0016714D^2] + [59.029 \left(\frac{P}{T}\right) - 3.0660 \text{ Date}] + [0.541D_2^3 - 55.57D_2 + R - 0.000031544D_3^3]
\]

where:

- \( y \) = total amount of soil moisture (in percent by volume) for the first 3 feet.
FIGURE 25. Diagram of bedrock and distance variables used in the soil moisture statistical model.
LBD = local bedrock depth, the depth in feet from the surface to bedrock at a particular tube.

MBD = minimum bedrock depth, the shallowest bedrock depth at some distance downslope from a particular tube.

$D_1$ = the downslope distance in feet from a tube to the point of minimum bedrock depth.

Date = the chronological date, i.e., July 21 = 202 for a non-leap year.

$P/T$ = The precipitation ($P$) for a given storm divided by the time ($T$) in days since the last storm.

$D_2$ = slope distance in feet from the particular tube to a reference point 26 feet above the uppermost tube in the block. As used in the equation, $D_2$ is divided by 100.

$R$ = a road constant. $R = -38.83, 0$, and $+38.83$ for the upper, middle and lower subblocks, respectively.

$D_3$ = the slope distance in feet from the center of the nearest road to a particular tube. $D_3$ is $+$ if the tube is above and $-$ if below the nearest road.

The first set of brackets contains the bedrock variables that affect soil moisture. The first term in the brackets indicates that as minimum bedrock depth decreases relative to local bedrock depth (i.e., the bedrock surface converges on the soil surface), soil moisture increases. The last three terms in the brackets indicate that as the distance to minimum bedrock depth increases, soil moisture decreases.

The second set of brackets contains the precipitation and date variables and indicates that soil moisture increases with precipitation and decreases
throughout the season as the date increases. Figure 26 shows how precipitation and date affect soil moisture with all other variables held at their mean values.

The third set of brackets contains the downslope distance and the road variables. The net effect of these variables is a decrease in soil moisture from the upper to the lower road. Figure 27 shows the field observations of soil moisture averaged for the seven 1963 measurement dates. When soil moisture is predicted for the same observed dates using the actual bedrock depths, the downhill distances and road variables, and then averaged for each tube and plotted, the scatter of the original data is much reduced. Both the observed and predicted points show a decrease in soil moisture downhill. Figure 28 was developed with all the variables held at their mean values for prediction purposes. The brief analysis to date cannot show whether this soil moisture decrease from the upper to the lowest road is caused by the cumulative effect of 3 insloped roads.

Full evaluation of treatment effects will be made using the field data taken in 1964. The 1963 data will be screened to remove all tubes which yield erratic data caused by voids adjacent to the tube wall. This "pruning" of the soil moisture data for evaluation of treatment effects should reduce the variance in soil moisture and make treatment evaluation easier.

SEEPAGE FLOW

Seepage flow during the summer season follows a recession curve interrupted only by periods of precipitation. A typical hydrograph of seepage flow during a rainy period is shown in Figure 29. The peaks are
FIGURE 26. Predicted soil moisture response to precipitation
FIGURE 27. Scatter of soil moisture values about 3 insloped roads in a clearcut block
SOIL MOISTURE BY VOLUME - SUM OF FIRST 3 FEET

BLOCK I
1963

FIGURE 28. Soil moisture prediction equation applied to the upper road of a clearcut insloped roaded block
FIGURE 29. Seepage response to rain
caused by rain in the trough itself, but a net rise in base flow from September 13 to September 15 is indicated.

In June 1964, seepage flow measurements were begun on four subblocks to estimate the amount of seepage that would be required to be safely disposed of from logging roads during the snowmelt season. The 1964 measurements began after snowmelt had commenced so the 1965 snowmelt hydrograph is shown (Figure 30) as an example of seepage flow for the complete snowmelt season. This hydrograph was planimetered to yield the snowmelt seepage volume of 1.3395 second-foot days for 25 days, or 0.1061 acre-feet per day for 100 feet of road section. The tributary area cannot be readily defined, but an estimated area of 100' by 400' is not unreasonable for the upper road of Block 1. Applying the estimated tributary area of 0.0014 square miles to the average seepage flow rate yields 75.8 acre-feet per square mile per day. The measured flow volume excludes a large percentage of overland flow and hence these figures reflect the subsurface contribution to streamflow during the snowmelt season. The overland flow barriers were designed for summer storms so it is not known how effective they are for diversion of overland flow from snowmelt. The overland flow barriers were removed during the fall of 1966 on three of the four subblocks so that future measurements during the snowmelt season will give total snowmelt runoff through and over the road cut and also an estimate of the percentage of this runoff which occurs as overland flow.

HYDRAULIC CONDUCTIVITY

Results of the hydraulic conductivity measurements were accepted at face value until an alternate method could be developed as a check.
FIGURE 30. Subsurface seepage for 1965 snowmelt season from 100 feet of insloped road in clearcut area
Personnel of the University of Idaho were persuaded to use the study area as a test site for studying fluorescent dyes in groundwater movement. In 1965, a graduate student injected two types of dye (Figure 12) in a number of groundwater wells on the study area and found the average groundwater velocity was 9 feet per day. The average water velocity derived from the pumped-well method in this study was 3 feet per day. Dye tests underestimate flow velocities because of dye adsorption; therefore, the difference in velocity from the pumped-well data and the dye study becomes even larger. The probable source of this error is excessive head loss when the water enters the central pipe in the pumped well. A method for checking hydraulic conductivity would be to attach a siphon to a well with head adjusted so as to yield a sustained flow rate, then another well can be used to measure the drawdown caused by this pumping rate. Reliable methods can be used to determine the hydraulic conductivity. The results of hydraulic conductivity measurements from the pumped wells used in this study would suggest that a larger central pipe should be used in the pumped wells to minimize the entrance head loss.

PRECIPITATION MEASUREMENTS

Precipitation data from the weighing recording gages for 1963 through 1965 were analyzed to develop an estimate of forest canopy interception. A prediction equation was developed to yield precipitation under the forest canopy ($P_f$) for a given value of precipitation in the clearcut ($P_c$) (Figure 31). The intercepted precipitation fraction is determined by subtracting the ratio $P_f/P_c$ from 1.00. When the intercepted precipitation fraction is plotted against the clearcut precipitation, the relationship of interception to precipitation results (Figure 32).
FIGURE 31. Forested - clearcut precipitation correlation
FIGURE 32. Interception of precipitation by a mature spruce-fir forest.
CHAPTER VII
SUMMARY AND CONCLUSIONS

Results of the soil moisture phase of the study were confounded by the unforeseen effect of bedrock depth which will make evaluation of treatment effects difficult. The experimental procedure for future studies should be altered to select study areas on the basis of seismic uniformity to avoid the problem of nonuniform bedrock conditions (9,10). The effect of the road on soil moisture does not seem to be as pronounced at the road cut and the road fill as assumed in the experimental design. The concentration of soil moisture tubes at the road causes more weight to be given to measurements farther from the road. Had the tubes been distributed more uniformly over the area, the prediction equation would have been better defined for the interval between roads.

Procedures used for installing access tubes undoubtedly will contribute to unexplained variance in analysis of soil moisture data. The use of heavy equipment to drill holes in rocky ground can be definitely recommended.

The design and installation of equipment for measurement of seepage flow was generally successful. Measurements of seepage flow during the snowmelt season have shown the potential for logging roads to adversely affect the streamflow hydrograph if a drainage is intensively roaded. This portion of the study should be expanded and replicated on other exposures and bedrock conditions to more fully define the hydrologic effect of logging roads. Future seepage flow studies should attempt to limit or at least define the tributary area of overland flow and subsurface flow.
The measurements of hydraulic conductivity were not accurate because of poor design of pumping wells. The pump-manometer has not been shown to be faulty and should be tried again with a better well design to see if this is a fast and accurate way to measure hydraulic conductivity in the field.

Precipitation measurements were good and the canopy interception curve seems to be reasonable. Two or more precipitation gages in the forested areas would yield a better estimate of canopy interception.
APPENDICES
APPENDIX A

SAMPLE FIELD DATA SHEET FOR SOIL MOISTURE
### Neutron Soil Moisture Data Sheet

#### Tube No. 001 Year 1963

**1-Minute Counting Time**

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### Sample Field Data Sheet

#### Neutron Soil Moisture Data Sheet

**Tube No. Year**

**1-Minute Counting Time**

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#### Suggested Revision of Field Data Sheet

**Figure 33. Sample field data sheet for soil moisture**
APPENDIX B

CALIBRATION PROCEDURE FOR THE PUMP-MANOMETER
APPENDIX B

CALIBRATION PROCEDURE FOR THE PUMP-MANOMETER

The pump-manometer developed for this study uses an air-liquid column to indicate rise of water in the pumped well. To correctly indicate well-water levels, the manometer scale must be calibrated for changes in the length of the air column as the liquid level changes. The liquid used in the manometer was alcohol with a small amount of dye added. The temperature of the ground water on the study area remained at 38°F. for most of the field season. Therefore, this calibration procedure was carried out in the early morning hours when the air temperature was in the low 40's. During calibration the instrument was immersed in spring water at from 36° to 38°F.

The conduit was scored at 1-inch intervals beginning at the manometer inlet. The instrument was inserted in a long glass tube and water was poured into the tube until the level reached the manometer inlet. The scale was adjusted until the scale zero was aligned with the liquid level in the manometer. Next, more water was poured into the glass tube until the level reached the first inch mark and the scale was scribed to correspond to the 1-inch level. This process was repeated until the scale had been completed.

When the pump-manometer is in use, most of the body of the instrument is in the low temperature environment of the ground water well and only the top of the manometer is exposed to the higher air temperature. No thermal effects were noted as long as the exposed portion of the manometer was shaded from the direct heat of the sun.
LITERATURE CITED


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NAME AND ADDRESS

Burroughs, E. R.

Design and installation of...