A METHOD OF FOREST SOIL-SITE QUALITY INVESTIGATION

by

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I. INTRODUCTION

Timber is a crop of the soil. Not all soils are of equal value for timber growth. The forester realizes that "rough stony" or "rough mountainous" land is no longer an adequate description of forest soils. Due to the low value of forest lands, soil surveys have not been made on forest soils of the Pacific northwest.

As second-growth timber becomes more important to the economy of the northwest, forest management practices will become more intensive. As the management becomes more intensive, greater attention must be paid to the part soil plays in the regeneration and growth of the forest crop. With soils of greater growth capacity, more intensive forest management is justified.

Within the past few decades an increasing amount of research has been directed towards establishing relationships between timber growth, physiography, and soils. Some relationships have been found between site quality and certain forest soil characteristics. However, results of these studies indicate there is a great need for further work in this field.

II. THE PROBLEM

The Bureau of Land Management (BLM) provided a grant to establish a study project designed to develop a forest soil inventory method suitable for use with the BLM timber inventories. As stated in the memorandum of understanding the objectives of the project are:[1]

1. To develop techniques and methods of surveying and mapping forest soil conditions on a broad inventory basis.
2. To investigate the uses of aerial photos in forest soil surveying and mapping.
3. To provide information that will be a foundation for further forest soils investigations aimed at correlating forest soil classification with accepted forest management practices and establishing bases for evaluating forest site classes and indices with soil conditions.

1 Memorandum of understanding between the Bureau of Land Management and Oregon State College relative to proposed soil survey project. January 18, 1955.

III. REVIEW OF LITERATURE

This review deals with the literature on factors to be considered in forest soil surveys. Methods used in current site quality-forest soil surveys will be reviewed. The relationships found between forest site quality, soils, physiography, precipitation, and vegetation will be discussed.

FACTORS TO BE CONSIDERED

Lunt and Swanson (20, pp.265-278) state the main soil factors to be examined in forest soil-site correlations are: texture, color, consistence, structure, thickness, soil pH, and moisture relations. Slope, humus type, and current land use are additional factors to be considered. They found that soil type, slope, aspect, moisture relations, humus type, and amount of stones influenced site quality in Connecticut. Retzer (24, pp.615-619) concludes that a survey of physical factors of soils, topography, and rock type will supply basic information for site evaluation in the Rocky Mountain area. He includes kind and density of timber, soil texture groups, depth of soil to bedrock or an impervious layer, fertility, and erodability of the soil as factors to be examined. Soil texture, depth, and degree of profile development were used as the basic soil characteristics studied on the Angeles National Forest in California (9, pp.755-762). The survey methods used will vary according to the purpose of the survey, local conditions, and the amount of time allowed for completion.

SOIL SURVEY TECHNIQUES

The procedures used in conducting current soil surveys in California and Washington are discussed.

CALIFORNIA

The U. S. Forest Service, California Forest and Range Experiment Station is currently conducting soil vegetation surveys on upland areas in that state (14, pp.151-157; 30, pp.499-509; 42, pp.521-526). The procedure is to delineate vegetative and land features on aerial photographs. These areas are then classified in the field by vegetative species, timber site quality, soil series, and soil depth. Topography and kind of parent material are recorded. Soils are broken down into the factors of color, texture, permeability, drainage features, and soil acidity.

When completed, all factors are compiled into vegetation-soil maps showing dominant plant species, site quality, soil series, and soil depth. The field manual of soil-vegetation surveys in California (39) gives a detailed description of all procedures.

WASHINGTON

The U. S. Forest Service and the Washington Agricultural Experiment Stations are cooperating on a project to gather soil engineering information and to determine soil classification on several million acres of upland "wild" lands in that state (41, pp.1-22). The method consists of delineating landform units on aerial photographs. These units give an excellent clue as to the type of soil material. Landform also furnishes clues as to texture, mode of deposition, and depth of the soil material.

Field notes taken on the soils include depth, texture, and character of the profile. Topographic features and the type of vegetation are recorded. Any relationships that form a repetitive pattern across the landscape are noted. This method of survey makes considerable use of landform factors taken from aerial photographs and field work is primarily to correlate and check the photo interpretation.

INVESTIGATIONS OF FACTORS RELATED TO SITE QUALITY

Research studies that show the correlations between forest site quality and the environmental factors of soils, physiography, precipitation, and vegetation are discussed below.

SOILS

Soil nutrients are not usually a limiting factor in tree growth (3, p.598; 11, p.719; 12, p.4; 17, p.837). For these reasons the remaining portion of this review of literature is concerned with only the physical characteristics of the soil. Specific properties of the soil that have been found to be related to site quality by various investigators include: depth, texture, consistence, drainage, and erosion. The factors are discussed in that order.

DEPTH Auten (3, pp.593-596), working with black locust (*Robinia pseudoacacia* L.) and black walnut (*Juglans nigra* L.) in the midwest, found significant correlations between site quality and the thickness of the A horizon for both species. The same author (2, p.667), working with yellow poplar (*Liriodendron tulipifera* L.) also found a correlation between site quality and depth to a tight subsoil. In both cases, site quality increased as depth increased. Roberts (25, p.584) reports that height growth increases with increasing depth to a clay layer for young planted black locust in Mississippi.

A significant relationship of increasing site quality with increasing depth was reported from work with oaks (*Quercus spp.* L.) in Iowa (11, p.723) and loblolly pine (<u>Pinus taeda</u> L.) and shortleaf pine (<u>Pinus echinata</u> Mill.) in the south (8, p.70 and 13, p.275). Site quality was also found to increase with soil depth to bed rock or an impervous layer for eastern red cedar (<u>Juniperus virginiana</u> L.) in the Ozarks (1, p.511).

Turner (35, p.10) indicates that depth of the soil influences soil moisture, hence effects site quality in Arkansas. The deeper the soil, the more available moisture. Ralston (23, p.412) found the depth to subsoil mottling an important factor in the growth of longleaf pine (<u>Pinus palustris</u> Mill.) on poorly and imperfectly drained soils. Young (43, p.86), working with white pine (<u>Pinus strobus</u> L.) in Maine, found site index to decrease with an increase of total depth of the A horizon.

Storie and Wieslander (30, pp.501-502) report that for high rainfall areas of California, soil depth is the limiting factor in nearly all instances where site quality is low. In southwest Washington, Carmean (4, p.334) found Douglas-fir (<u>Pseudotsuga menziesii</u> (Mirb.) Franco) site quality to increase with depth to the C horizon. Gessel (15, p.334) states the site index of Douglas-fir increased from 156 to 178 when the depth to an impenetrable layer in a medium textured soil of low gravel content exceeded twenty four inches. Lemmon (19, p.328) found Douglas-fir site indices to increase with an increase of total effective depth on south and level aspects for residual hill soils of medium texture in the Willamette basin of Oregon.

TEXTURE Stoeckler (29, p.728), working with quaking aspen (*Populus tremuloides* Michx.) in Wisconsin, and Chandler, Schoen, and Anderson (5, p.505) with loblolly and shortleaf pine in east Texas, conclude that texture, as it reflects water holding capacity, is the primary soil characteristic influencing site quality. Young (43, p.86) found site index of white pine in Maine to decrease with an increase in per cent of stones found in the B horizon.

Holtby (18, pp.824-825) found that soil texture at a depth of six inches below the surface proved to be a fairly reliable indicator of site quality for ponderosa pine (*Pinus ponderosa* Dougl.) in southeast Washington. He further states that soil texture does not provide a reliable method of site determination in the Douglas-fir region of western Washington where topography is extremely rough.

Gessel (15, pp.334-336) reports that for the thirty five to forty five-inch rainfall belt of northwest Washington, coarse textured surface soils gave an average site index of 125, light textured soils an average site index of 150, and medium textured soils an average site index of 176. For the forty five to sixty-inch rainfall belt, site index increased from 117 for coarse textured surface soils to 143 for light textured surface soils, and to 170 for medium textured surface soils. In southwest Washington, Carmean (4, p.334) found site quality to decrease with increasing amounts of gravel in the soil and with increasing compaction. A study in Lewis county, Washington by Hill, Arnst, and Bond (17, p.837) showed that the ability of the soil to retain moisture during the growing season is the most important soil factor relating to site quality. They conclude that this ability is not only a function of texture and permeability, but also of depth.

CONSISTENCE Auten (3, pp.593-594) found the plasticity and compactness of the subsoil to be significantly related to site index. The higher the plasticity and more compact the soil, the lower the site index. A dense B horizon was also found to reduce site quality for pines in east Texas (5, p.506).

DRAINAGE Storie and Wieslander (30, p.505) report from work in California that high sites occur on well drained soils. Imperfect drainage appears to lower site values as much as ten to forty per cent. Tarrant (34, pp.1-4) cites work done at the Pringle Falls Experimental Forest to show an apparent relationship exists there between subsurface drainage and forest type. On areas of impeded subsurface drainage, stands of lodgepole pine (*Pinus contorta* Dougl.) are found, while on well drained areas the forest type is predominatly ponderosa pine. Hanzlik (31, pp.65-66), working in Oregon and Washington, found that the best growth of Douglas-fir occurs on slopes with good drainage and in medium to deep loam soils with gravelly or sandy subsoils.

EROSION Cooper (10, p.710) found a correlation between site quality and amount of erosion in South Carolina. The more eroded the soil, the lower the site quality.

PHYSIOGRAPHY

Coile (8, p.70) failed to find a correlation between topography and site quality in the loblolly and shortleaf pine area of North Carolina. Cooper (10, p.710) came to the same conclusion from studies in South Carolina. Auten (2, p.665) states that, "Topography, through its three elements of aspect, exposure, and position, modifies soil moisture content; hence it has an important effect on site quality."

Aspect, slope, position on slope, slope form, and elevation have been found correlated to site quality by other workers. They are discussed in that order.

ASPECT Einspahr and McComb (11, p.723) found that north and east aspects give higher site indices for oaks in Iowa. Gaiser (12, p.4) reports that superior sites are on northeast exposures for white oaks in Ohio.

SLOPE Site index was found to decrease as per cent of slope increased for oaks in Iowa (11, p.723). Turner (35, p.11) indicates that slope and exposure influence available moisture in the soil in Arkansas. Lemmon (19, p.328) found that site quality for Douglas-fir decreased with an increase of slope in the Willamette basin of Oregon.

POSITION ON SLOPE Gaiser (12, p.4) states that lower slopes give highest sites for white oaks in Ohio. Site quality decreases rapidly in the vicinity of the ridgeline.

SLOPE FORM Tarrant (32, p.724) reports that concave topography is associated with significantly higher site quality than is convex topography in western Washington.

ELEVATION Carmean (4, p.334) found in southwest Washington that site quality for Douglas-fir decreased with increasing elevation. Lemmon (19, p.328) indicates that site quality decreases with elevation in the Willamette basin. A limited study in Tillamook county, Oregon by Ward and Collins (40, p.2) revealed that elevation is the only limiting factor of site quality for that high rainfall area.

PRECIPITATION

Hill, Arnst, and Bond (17, p.837) report that site indices of Douglas-fir average about thirty points higher in the sixty to ninety-inch rainfall belt of southwest Washington than in the forty five to fifty five-inch belt. Gessel (15, pp.334-336) concludes however, that forty inches of rain is sufficient to bring the soil to field capacity in northwest Washington. Any further increase may reduce site quality by excessive leaching. Lemmon (19, p.328) shows that Douglas-fir site quality increases with an increase in total annual precipitation on south and level aspects in the Willamette basin. Site quality increases in direct relation to rainfall from about forty to one hundred inches of rain.

VEGETATION

Classification of forest site quality on the basis of understory vegetation has received much attention. Lutz and Chandler (21, pp.433-435) present a good resume of this subject. Coile (6, pp.1063-1065) questions the use of vegetation as an indicator of site quality. He bases his objections on the fact that competition, characteristics of the forest stand, soil nutrients, and parent material may influence the ground cover, but not the overstory. Understory species have been found however, both in the eastern and western parts of the country, that provide indicators of site quality for specific areas.

EAST Stoeckler (29, p.734) mentions the height of bracken fern (Pteridium spp. Scop.) as an indicator of soil moisture conditions in Wisconsin. Coile (7, p.730) states that flowering dogwood (Cornus florida L.) is seldom found on poor sites in the south, but is common on good sites.

WEST Wieslander and Storie (42, p.524) state there is a general relationship between vegetation, climate, and great soil groups in California. Carmean (4, p.331) reports that a cover of sword fern (Polystichum munitum (Hault) Underw.) indicates relatively good sites for Douglas-fir in western Washington, while a cover of salal (Gaultheria shallon Pursh.) is an indicator of poorer sites. Spilsbury (28, pp.19-33) recognizes five vegetative indicator site types for Oregon, Washington, and British Columbia corresponding roughly to the five site qualities described by McArdle and Meyer (22, pp.11-13). The best sites are characterized by a dominance of sword fern and may leaf (Achlys tripylla D. C.), and the poorer sites by salal and Oregon grape (Mahonia nervosa Pursh.). All four species occur on all sites, but the relative abundance, vigor, and dominance of each species is significant.

SUMMARY OF LITERATURE REVIEW

Soil factors to be considered in a forest soil-site survey are listed as: texture, color, consistence, structure, depth, soil pH, moisture relations, degree of profile development, and fertility. Slope, aspect, erosion, amount of rock, humus type, timber type and current land use are additional factors to be considered. Soil surveys of upland areas in California and Washington are currently being conducted. Vegetative and landform features are delineated on aerial photographs. These areas are then classified in the field. The California survey classifies the areas according to vegetation, timber site quality, soil series, and depth. Topography and kind of parent material are recorded and the soils broken down into the factors of color, texture, permeability, drainage features, and soil acidity. Field notes taken on the Washington survey include depth, texture, and character of the soil profile, topographic features, and vegetation. Survey methods used will vary according to the purpose of the survey, local conditions, and the amount of time allowed for completion.

Several investigators have indicated that nutrients are seldom a limiting factor in tree growth. Physical soil properties of depth, texture, consistence, drainage, and erosion have been found to be correlated with site quality. Topographic features of aspect, slope, position on slope, slope form, and elevation have been found to be related to site quality. Correlations between the amount of rainfall and site quality have been found in the Pacific northwest. Vegetative indicators of site quality have also been found to be related to site quality in specific areas.

IV. PROCEDURES

The inventory area is described in this section. Preliminary work and the actual field procedures are discussed.

INVENTORY AREA

The location of the inventory area, a description of it, and the vegetation found is given.

LOCATION

The problem area was included within the Bureau of Land Management Quartzville Administrative Unit of the Santiam River Master Unit. The unit is located on the west slope of the Cascade mountains, about twenty five miles northeast of Sweet Home, Oregon (Figure 1). Due to the limits of time, accessibility, and field personnel, it was impossible to inventory the entire area. The actual inventory area was limited to that portion of the unit north of Quartzville Creek falling in Township 11 South, Ranges 3 and 4 East, Willamette Meridian. This comprised about nineteen thousand acres, located primarily on the south side of the divide between Thomas and Quartzville Creeks.

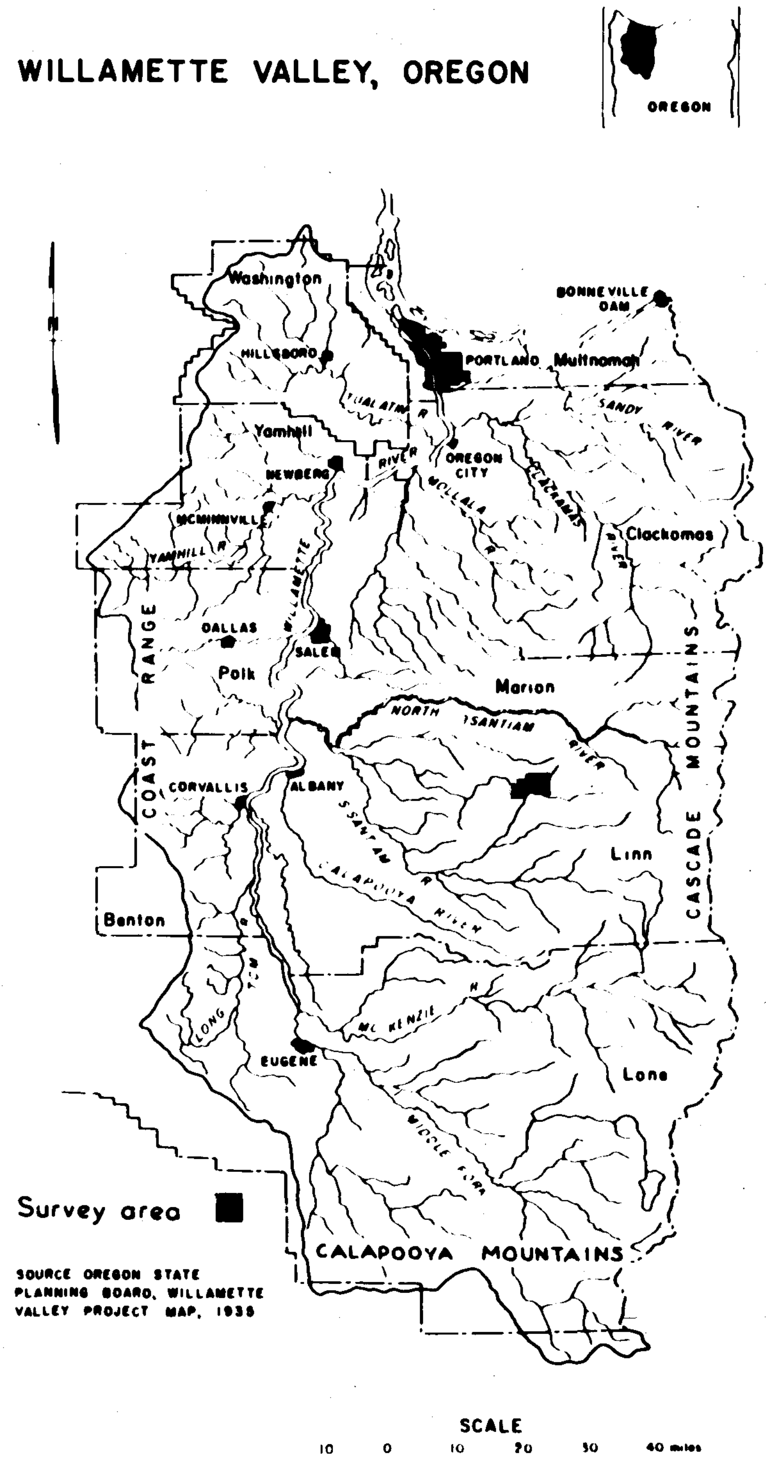

FIGURE 1. LOCATION OF PROJECT AREA

DESCRIPTION

The topography of the area is rough and broken with slopes on the sample plots averaging about 60 per cent. Elevation varies from about one thousand feet along Quartzville Creek to about four thousand five hundred feet on some of the main ridges. Figure 2 gives two general views of the area. The parent material is basic igneous basalt and andesite, with some andesitic tuff also found. Soils comparable to the Olympic Series were found at the lower elevations, however no soil survey has been made of the area, so the soils are considered unclassified.

Rainfall data were not available for the project area, however at an elevation of 861 feet along Quartzville Creek, several miles downstream from the area, the average rainfall for the years 1949-1954 was 94.05 inches (37). A high of 123.01 inches was recorded for 1953, and a low of 60.43 inches for the year 1952. By comparing these figures with an isohyetal map from the Portland District Office, Corps of Engineers, it appears that the project area receives about one hundred inches of rain annually. Considerable snow falls during the winter, especially at the higher elevations.

FIGURE 2. GENERAL VIEW OF PROJECT AREA

VEGETATION

The timber is predominatly old growth Douglas-fir from two hundred to six hundred years old. There are a few large stands of fifty to sixty year-old second-growth on the project area. Considerable western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) is found, especially on northern exposures. Noble and pacific silver fir (*Abies procera* Rehd.) and (*Abies amabilis* (Doug.) Forbes) are found at the higher elevations. Both sugar pine (*Pinus lambertiana* Dougl.) and western white pine (*Pinus monticola* Dougl.) are found on ridges and drier slopes, as well as some golden chinquapin (*Castanopsis chrysophylla* (Dougl.) A. DC.). The minor species, western red cedar (*Thuja plicata* Donn), pacific yew (*Taxus brevifolia* Nutt.), and bigleaf maple (*Acer macrophyllum* Pursh.) are also found scattered over the area.

Understory vegetation is similar to that encountered under most coniferous forests in western Oregon. This includes: Oregon grape, salal, huckleberry (*Vaccinium spp.* L.), vine maple (*Acer circinatum* Pursh.), Douglas maple (*Acer glabrum Douglasii* (Hook.) Dipp.), rhododendron (*Rhododendron macrophyllum* G. Don), sword fern, and bear grass (*Xerophyllum tenax* (Pursh) Nutt). Some blackberries (*Rubus spp.* L.) and red-flowering currant (*Ribes sanquineum* Pursh.) are found on dry sites, and devil's club (*Oplopanix horridum* (Sm.) Miq.) on moist sites.

PRELIMINARY WORK

As the soil inventory was to be carried on in conjunction with the regular BLM timber inventory, the same random samples were used for both the timber and soils inventory. These samples were marked on the appropriate aerial photographs by the Portland office of the BLM in accordance with the standard BLM inventory procedures (38, pp.19-20) and sent to the field crews for use. The appropriate photograph was selected by means of a random number table. A plot selector grid was then used with a second set of random numbers to locate the plot cluster on the photograph. The marked point was the center of the first of four plots, six chains apart. Before the field work started, the first plot of each cluster, which was the marked point, was examined stereoscopically and the aspect, position on slope, slope form, and degree of slope were estimated. These estimates were later checked by field examination.

The approximate elevation of each plot was taken from a twenty-foot contour map having a scale of 1:4,800. Elevation was classified as low (one thousand five hundred to two thousand five hundred feet), medium (two thousand five hundred to three thousand five hundred feet), and high (over three thousand five hundred feet). No field checks of elevation were made.

FIELD WORK

The inventory procedures and the methods used in taking the field data are discussed below.

INVENTORY PROCEDURE

The timber inventory was carried out by a two-man crew following the standard BLM inventory procedures (38, pp.22-23). The marked point on the aerial photograph was located as accurately as possible on the ground by using a pocket stereoscope and orienting with such features as natural openings, ridges, streams, and identifiable trees, after the procedures outlined by Heath (16, pp.34-37).

The marked point was the first of four one-fourth acre circular plots. The procedure called for the cluster of four plots, six chains apart, to be run in a cardinal direction, starting with north. If second-growth, logged areas, or large natural openings were encountered within twenty chains of the first plot, the line of plots was run to the east. If this direction was unsatisfactory, south was tried, and then west. Forest type lines may be crossed, but only so long as the plots still fall in merchantable timber. The procedures state that stands one hundred years old, or older, and residual stands of one hundred years and of medium or better stocking, are merchantable. In a few instances, plot clusters were run to the east to avoid open areas, current logging, or to prevent closely paralleling another series of plots.

INVENTORY DATA

At each plot center a data sheet (Figure 6, page 50) was filled out. Landform, vegetation, soils, site index, and timber volume data were recorded. By the time the inventory project was completed, 40 samples, or 160 plots, had been taken. This was considered a large enough sample for an analysis.

It should be pointed out that the observations taken were not of a refined nature, one reason being the time element. Due to travel time involved, both by jeep and by foot, it was necessary to inventory at least one sample of four plots each day. The maximum time allowed at any one plot was about one hour. This ruled out the possibility of any lengthy or exacting study of the soils or vegetation. The actual field data, other than timber inventory information, included measurements and observations of landform, vegetation, and soils.

LANDFORM Slope was determined to the nearest 2 per cent with an abney level by sighting along the average slope. If a difference existed between the uphill and downhill slope from the plot center, the uphill reading was taken since it was assumed the uphill slope had more influence on the plot. Aspect was recorded to the nearest five degrees by means of a hand compass. The form of the slope, both across and along the slope, was judged to be concave, flat, or convex. Slope position was estimated to be either creek bottom, lower, middle, upper slope, or ridgetop. These estimates were based on observations of the landform approximately one hundred feet in all directions from the plot center.

VEGETATION The tree species within each one-fourth acre plot were recorded and an ocular estimate made of the per cent of total plot area covered by the crown of each species to the nearest 5 per cent. Non-timber species, or understory vegetation, was treated in the same manner. By this method of estimating crown coverage, a total plot coverage of more than 100 per cent could be obtained if one species was found growing under another. This occasionally happened for the understory vegetation, but never occurred for the timber species.

No attempt was made to identify or record the ground cover such as oxalis or the annual flowers. Time and unfamiliarity with the numerous flowering species prevented it. In any future surveys of this kind, the feasibility of recording and classifying this ground cover should be considered.

SOILS At each plot center, or at a point within ten to twenty feet of the center, where surface conditions seemed to be about average, a hole was bored or dug to the C horizon. The plot center would often fall in a concentration of roots or on a pile of rock, making it necessary to move a few feet from the plot center to locate the soil sample hole. Occasionally a recent windfall would be close by, in which case the soil horizons might be exposed in the hole left by the roots. Then it was only necessary to dig away the material that had sluffed into the hole to get a good view of the soil profile.

Depth of the litter was recorded to the nearest inch, as was the depth of the A and B horizon. No breakdown of the soil horizons finer than A, B, and C was attempted. Soil texture was determined by wetting a small sample of soil and rubbing between the fingers. Structure was obtained by crumbling a sample and by observing the relatively undisturbed soil on the sides of the hole. Color of the three horizons was compared with color chips from the Munsell color charts[2] and recorded as the color of a moist soil. The consistence of the A and B horizons when wet was determined by wetting a sample and squeezing between the fingers. All procedures used in testing the soils and nomenclature used in describing them are in accordance with the methods set forth in the Soil Survey Manual (27, pp.173-216 and 225-234).

The kind of parent material was determined from samples taken from the test holes and rock found on the surface of the plot. An estimate was made as to whether drainage of the plot was good, fair, or poor. When rock and roots permitted, a four-inch soil auger was used to test for the presence of a hardpan or bedrock within a depth of three to four feet. However, the excessive amount of rock in the soil permitted only limited use of the auger. Special features, such as excessive moisture or excessive dryness of the soil were recorded, as well as the amount of shot and amount of rock encountered in the profile.

At the start of the project it was planned to classify the soil of each plot by tentative soil group or soil series at the time of sampling. Due to the great variety of soil features found, this was abandoned. No trends or natural groupings of factors could be found to

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2 Munsell Soil Color Charts. Munsell Color Company Inc. Baltimore, Maryland. 1946.

facilitate classifying the soils.

SITE INDEX AND TIMBER VOLUME Site index and total merchantable timber volume per plot were taken from the inventory data gathered by the BLM crew. Site index was calculated from McArdle and Meyers site quality curves (22, pp.11-13). There is some question as to the reliability of the site index values as only one Douglas-fir was measured per plot. A sixteen inch increment borer was used, therefore considerable extrapolation was needed to determine the age of trees over 32 inches in diameter. The site quality curves are drawn only to 440 years, injecting another source of error for trees over that age. For these reasons, all site indices were grouped into the five site qualities and these classes were used in all future calculations.

Total merchantable timber volumes per plot were taken from the inventory data and expanded to a per-acre basis. Cruise standards were in conformity with the BLM instructions (38, p.22).

V. ANALYSIS OF DATA

When the field work was completed, the data were examined and compiled. The procedures used in examining these data and the results found are discussed.

PROCEDURES

The soils inventory measurements were taken with a high degree of precision to permit more flexibility in the final analysis. Some of these data were of such a nature as to permit the grouping into broad classes. Others were used in their original form. The data for each plot were placed on an International Business Machine (IBM) punch card. The use of these cards permitted the screening out of those factors that had inconsistent variation or did not occur on enough of the sample plots to justify a test of their significance.

FACTORS TO BE TESTED

Minor regroupings were made in soil depth, texture, and per cent of vegetative cover. The breakdown of the factors used in the final analysis is described below.

LANDFORM Per cent of slope was combined into: gentle, (0 to 30 per cent), moderate, (30 to 60 per cent), steep, (60 to 90 per cent), and precipitous, (over 90 per cent). Aspect was divided into north, south, east, and west exposures. Elevation was previously combined into low, middle, and high elevations.

<u>VEGETATION</u> Site quality had no apparent influence on the per cent plot coverage of the overstory species so no further study was made of this factor. Understory species of Oregon grape, salal, vine maple, huckleberry, rhododendron, sword fern, and bear grass were used for the analysis. They were grouped into 10 per cent cover classes from 0 to 100 per cent.

<u>SOILS</u> Depth of the A and B horizons was arranged into two-inch classes. Soil textures were classed as heavy, medium, and light, as suggested by the Soil Conservation Service (36, p.32). One exception was made, in this study sandy clay loam was included as a light textured soil instead of medium textured. Table I indicates the grouping used. The amount of shot found in the profile was broken down into: no shot, less than 25 per cent shot, 25 to 50 per cent, 50 to 75 per cent, and over 75 per cent shot in each of the horizons. The same groupings were used for the amount of gravel and cobbles found in the three horizons.

TABLE I

SOIL TEXTURE GROUPS

Texture Group	Texture Class
Heavy	clay, silty clay
Medium	silty clay loam, silt loam, clay loam, sandy clay
Light	sand, sandy loam, sandy clay loam

On the basis of the card count, soil color, depth of litter, kind of parent material, and drainage features were not used in the final analysis. There was either inconsistent or not sufficient variation among these factors to warrant further study. The amount of rock on most plots prevented an accurate measurement of soil depth to bed rock, therefore this factor was not analyzed.

TEST USED

The test used was the Chi square (χ^2) test of independence, ($\chi^2 = \Sigma \frac{(x - m)^2}{m}$), when "x" is the number of field observations, and "m" represents the calculated theoretical number of observations (26, pp.204-205).

Each factor of landform, vegetation, and soil was placed in a two-way table and tested against site quality. If the results of the test were significant, site quality was dependent on the factor tested. Or in the case of the understory vegetation, the per cent of vegetation was dependent on site quality. The factors of landform tested were: slope, aspect, slope form, position on slope, and elevation. Understory vegetation tested was: Oregon grape, salal, vine maple, huckleberry, rhododendron, sword fern, and bear grass. Soil factors tested were: depth of the A and B horizons, depth of the combined A and B horizon, texture of the A, B, and C horizons, structure of the A, B, and C horizons, consistence of the A and B horizons, and per cent of rock and of shot in the A, B, and C horizons.

RESULTS

By the Chi square test, site quality was found to be significantly dependent on position on slope, depth of the A horizon, and structure of the B horizon. Per cent of sword fern, vine maple, Oregon grape, rhododendron, and bear grass found on each plot was found to be significantly dependent on site quality. All factors were significant at the one per cent level.

The factors found significant will be discussed. Other factors found significant at higher levels and apparent relationships found will be noted. Total merchantable timber volumes will be given.

POSITION ON SLOPE

A direct relationship was found between slope position and site quality. The lower the position on slope, the higher the site quality. Creek bottom plots averaged a high site quality III, lower slopes a middle to high site quality III, middle slopes a low to middle site quality III, upper slopes a high site quality IV, and ridgetops a low to middle site quality IV (Figure 3).

DEPTH OF A HORIZON

Depths of A horizons ranged from two to fourteen inches, with an average depth of 6.6 inches. The two-inch depth averaged site quality V, the four, six, eight, and ten-inch depths averaged a low to middle site quality III, the twelve-inch class a high site quality IV to low III, and the fourteen-inch class a middle site quality IV (Figure 4). The depth of the site quality II, III, and IV soils was very close to the average depth of 6.6 inches. The site quality I soils were found to be 0.7 inches deeper, and the site quality V soils 1.2 inches shallower than the average.

STRUCTURE OF B

As the size of the peds of the B horizon became larger, site quality increased. Soils with no B horizon

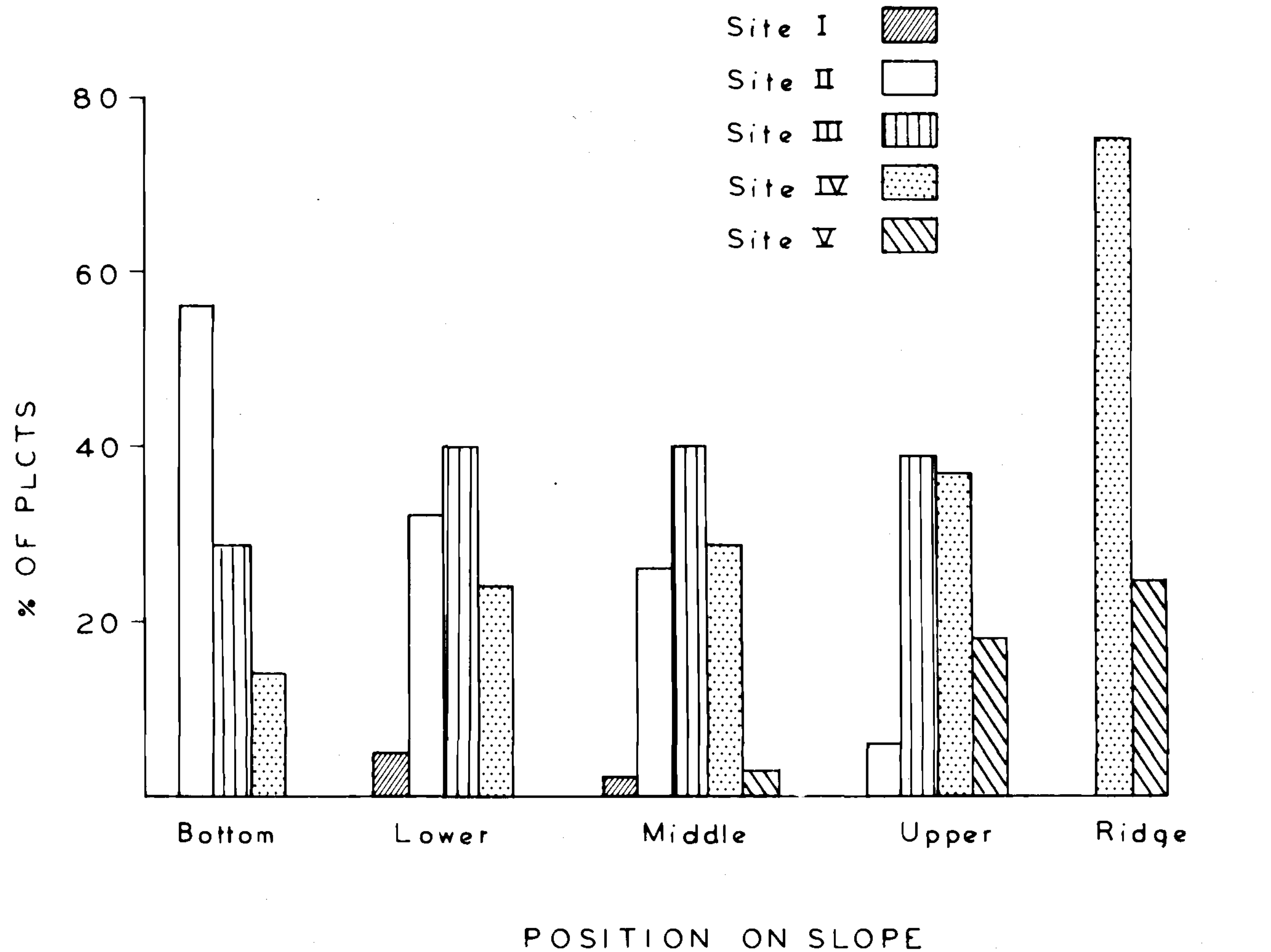

FIGURE 3. RELATION OF SITE QUALITY TO POSITION ON SLOPE

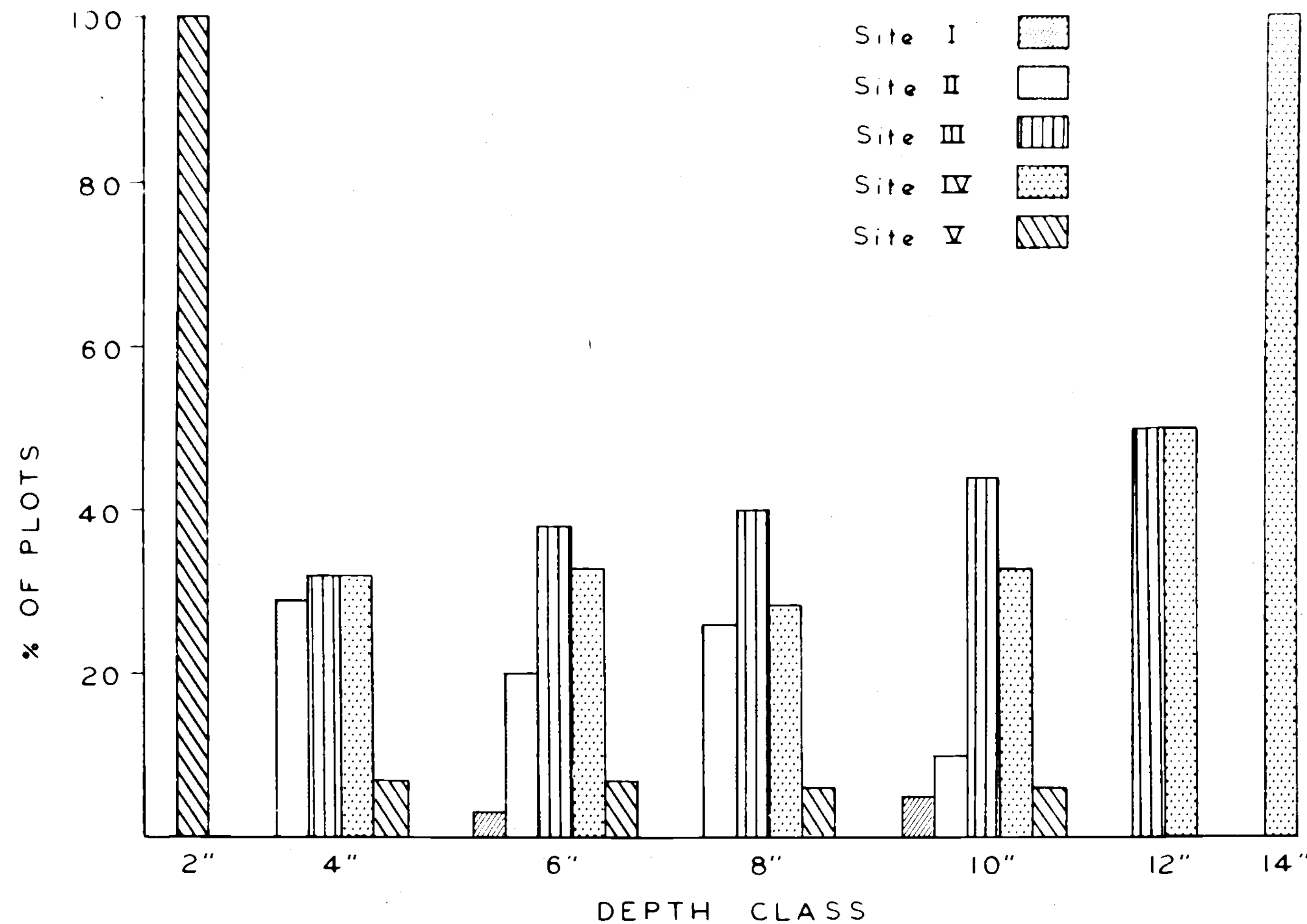

FIGURE 4. RELATION OF SITE QUALITY TO DEPTH OF A HORIZON

averaged a middle to high site quality IV, very fine subangular blocky structure averaged a high site quality IV, fine subangular blocky structure averaged a medium to high site quality III, and medium subangular blocky soils averaged a high III to low II site quality (Figure 5).

UNDERSTORY VEGETATION

The per cent of sword fern, vine maple, and Oregon grape on each plot increased with an increase of site quality. The per cent of rhododendron and bear grass on each plot decreased as site quality increased.

The per cent of sword fern found on each plot increased in the order of 0, to 5, to 10, to 15, to 20 per cent as site quality increased from site V to site I. Vine maple increased from 5 per cent on site quality V plots, to 20 per cent on site quality IV, to 30 per cent on site quality III, and to 35 per cent on site quality I and II plots. The per cent of Oregon grape found increased from 5 per cent on site quality V, to 15 per cent on site quality II, III, and IV, and to 35 per cent on site quality I plots.

Rhododendron decreased from a total plot cover of 55 per cent, to 30 per cent, to 15 per cent, to 10 per cent, to 5 per cent as site quality increased from site quality V to site quality I. The amount of bear grass

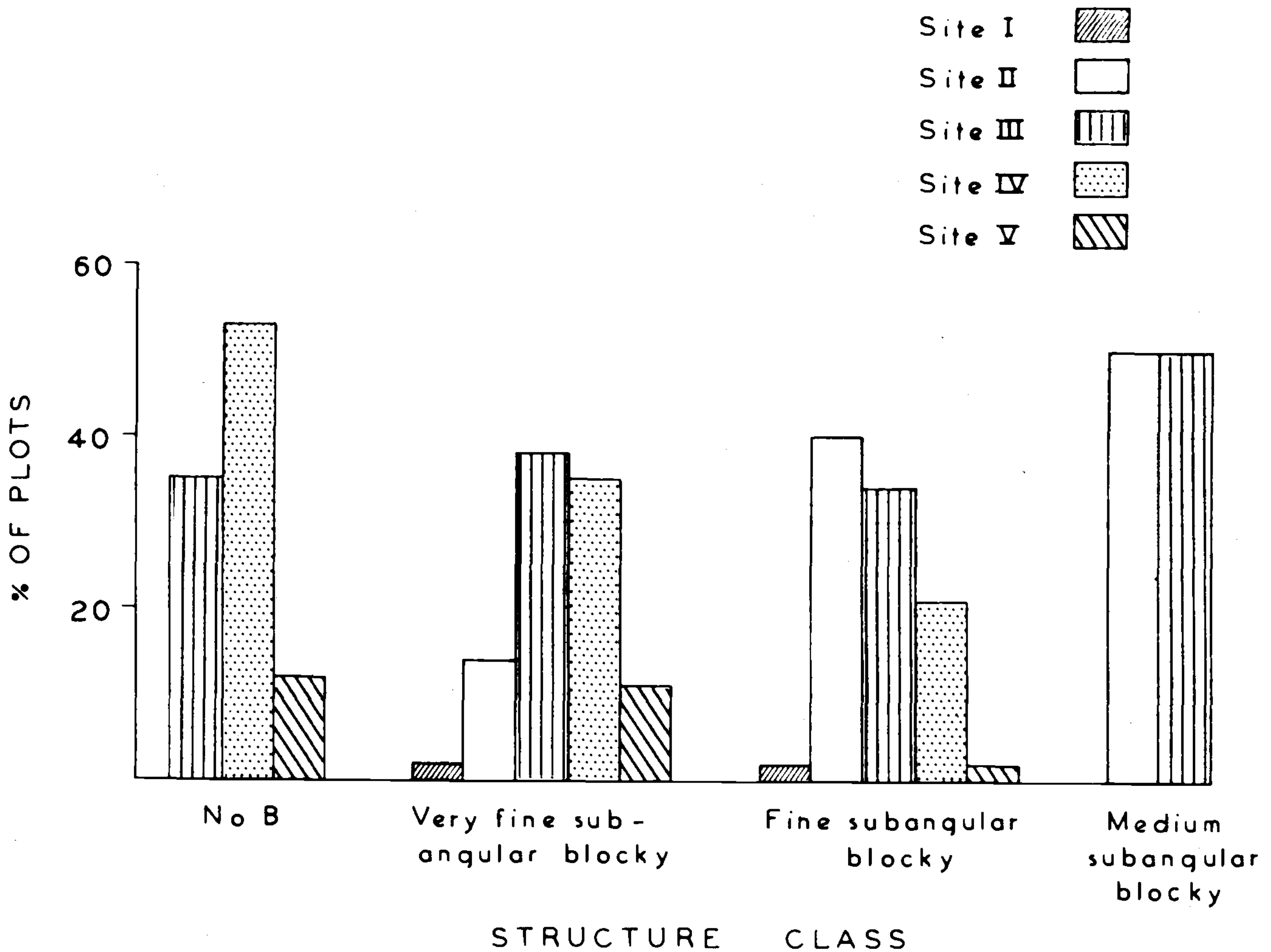

FIGURE 5. RELATION OF SITE QUALITY TO STRUCTURE OF B HORIZON

per plot decreased from 15 per cent on site quality V plots, to 10 per cent on site quality IV, to 5 per cent on site quality II and III plots, to 0 per cent on site quality I plots. All figures are to the nearest 5 per cent. Table II shows the percentage change with site quality for each species.

Plot coverage for any one plot varied from 0 to 90 per cent for vine maple and rhododendron, from 0 to 60 per cent for Oregon grape and sword fern, and from 0 to 40 per cent for bear grass.

TABLE II

RELATION OF SITE QUALITY TO PER CENT PLOT COVERAGE OF UNDERSTORY SPECIES

Species	Site Quality				
	I	II	III	IV	V
Sword fern	20%	15%	10%	5%	0%
Vine maple	35	35	30	20	5
Oregon grape	35	15	15	15	5
Rhododendron	5	10	15	30	55
Bear grass	0	5	5	10	15

OTHER FACTORS

Slope form, consistence of the A and B horizons, and texture of the C horizon were found to be related to site quality between the 5 and 15 per cent levels of significance. Shallow soils without a B horizon, or soils on which no B horizon could be determined, were classed as lithosols. These soils were not statistically analyzed, but by inspection certain trends were evident. These factors are discussed below.

SLOPE FORM Concave slopes were found to average a low to middle site quality III. Flat and convex slopes averaged a low site quality III.

CONSISTENCE The trend was for higher site quality to be associated with more sticky and plastic soils in the A horizon. Non-sticky and non-plastic soils averaged a high site quality IV, slightly sticky and slightly plastic soils averaged a middle site quality III, and sticky and plastic soils averaged a high site quality III.

The same trend was noted in the B horizon. Non-sticky and non-plastic soils averaged a middle site quality IV, slightly sticky and slightly plastic soils averaged a low site quality III, and sticky and plastic soils averaged a middle site quality III.

TEXTURE Site quality changed from a middle site quality III for heavy textured soils to a low site quality III for medium and light textured soils.

LITHOSOLIC SOILS Several plots were encountered with an A-C horizon. Either the B horizon was totally lacking or the amount of rock present prevented identification of a B horizon. No statistical analysis was made of these soils, however the lithosols averaged a middle to high site quality IV, while the average site quality of all plots, lithosols included, was a low to middle site quality III. Seventy per cent of the lithosols were found on steep or precipitous slopes, and a majority of them on south and west aspects.

TIMBER VOLUME

Merchantable timber volumes of all species were obtained from the timber inventory data. These figures were not statistically analyzed, but the relationship of timber volume to site quality is evident. Volumes averaged one hundred six thousand, four hundred board feet per acre for site quality I plots, ninety three thousand, eight hundred board feet per acre for site quality II plots, eighty seven thousand, six hundred board feet per acre for site quality III, sixty eight thousand, eight hundred board feet per acre for site quality IV, and sixty three thousand, six hundred board feet per acre for site quality IV plots.

VI. PHOTO INTERPRETATION

The landforms found in the field for the first plot of each plot cluster were compared with the values taken from the aerial photographs by stereoscopic means. Aspect was estimated from the photographs as either north or south. When the field observations were grouped as north or south, it was found that the correct aspect was missed on only three of the forty plots. Position on slope was missed on fifteen of the forty plots, slope form was missed on twenty two of the forty plots, and ocular estimates of the degree of slope were incorrect on twenty six of the forty plots.

The forest canopy tended to cover small ridges and depressions making them appear unimportant on the photographs although they were quite important on the ground. This produced a rather wide spread in the errors of slope form and position on slope. Degree of slope was difficult to interpret as displacement on the photographs gave a distorted view of the actual slope. Of the twenty six plots incorrectly interpreted, nineteen of them were found to be identified one class low.

All photo interpretation errors could undoubtedly be reduced with practice and by the use of mechanical aids to facilitate office measurements.

VII. SUMMARY AND CONCLUSIONS

A forest soil-site quality study was made of a portion of the Bureau of Land Management (BLM) Quartzville Administrative Unit in Linn county, Oregon. The random sample plots used for the BLM timber inventory were studied for landform, vegetation, and soils. Landform factors recorded were: aspect, degree of slope, slope form, and position on slope. Elevation was taken from twenty foot topographic maps. Vegetative factors included the per cent of crown cover per plot for overstory and understory vegetation, site quality, and total merchantable timber volume. Soil factors included: depth of litter, depth of the A and B soil horizons, texture, structure, and color of the A, B, and C horizons, and consistence of the A and B horizons. The kind of parent material, degree of drainage, depth to bedrock or hardpan, per cents of shot and rock in the profile, and any special features were also recorded.

These data were card counted by International Business Machine methods and the results tallied. This permitted the screening out of those factors that had excessive variation or were not found on enough plots to justify further tests. The remaining data were tested for independence of site quality by the Chi square test, ($\chi^2 = \sum \frac{(x - m)^2}{m}$), when "x" is the number of field observations, and "m" represents the calculated theoretical number of observations.

The factors of landform tested were: elevation, degree of slope, aspect, slope form, and position on slope. The vegetative factors tested were per cent of plot coverage of: Oregon grape, salal, vine maple, huckleberry, rhododendron, sword fern, and bear grass. Soil factors tested were: depth of the A and B horizons, depth of the combined A and B horizon, texture of the A, B, and C horizons, structure of the A, B, and C horizons, consistence of the A and B horizons, and per cent of rock and shot in the A, B, and C horizons.

Site quality was found to be significantly dependent on position on slope, depth of the A soil horizon, and structure of the B horizon. The per cent of sword fern, vine maple, Oregon grape, rhododendron, and bear grass on each plot was found to be significantly dependent on site quality. All factors were significant at the one per cent level.

Site quality increased as the position on slope changed from ridgetop to creek bottom. Both very deep and very shallow A horizons gave poorer site quality. In the present study it was found that site quality II, III, and IV soils had an average A horizon depth of about 6.6 inches. Site quality I soils were slightly deeper and site quality V soils shallower than 6.6 inches. Site quality also increased as the size of the peds in the B horizon increased. Soils with no B horizon gave the lowest site quality. Site quality increased as the structure changed from very fine subangular blocky to medium subangular blocky.

The per cent of sword fern, vine maple, and Oregon grape found on each plot increased with increasing site quality. The per cent of rhododendron and bear grass per plot decreased with increasing site quality.

At levels of significance between 5 and 15 per cent, site quality was found to be dependent on slope form, consistence of the A and B horizons, and the texture of the C horizon. Site quality was found to be slightly higher on concave slopes than on convex or flat slopes. Site quality increased with increasing stickiness and plasticity of the A and B horizons and with heavier textures in the C horizon.

As pointed out in the review of literature, moisture conditions are considered to be of great importance in their influence on site quality. Landform and soil factors found related to site quality in this study also tend to influence moisture conditions. The species of vegetation found significant undoubtedly reflect moisture conditions in the soil.

This project was of an exploratory nature and not all of the objectives of the project could be fully accomplished within the time available. The correlation of forest soils and site quality was done and a limited photo interpretation study was made of landform factors. For specific soil correlations, or surveys, a more thorough study should be made, with attention paid to specific landform factors and their relation to the soil properties.

If further studies of this kind are attempted, the method of site index determination should be re-examined. The current method is liable to several errors. If possible, a longer increment borer should be used and more than one tree per plot measured. Possibly the site index of the four plots per sample should be averaged. Accuracy could also be increased by extending the site index tables to stands of six hundred years of age.

From the results of this study it appears that site quality investigations relating to landform, vegetation, and soils are feasible by the method described. By statistical means, new factors that are related to site quality can be found for each area studied. Photo interpretation will allow estimates of site quality as related to landform factors to be expanded over larger areas than the actual inventory area.

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APPENDIX

FIGURE 6. SAMPLE COMPILATION SHEET

Salem DFO
June 20, 1955

Forest Soil Inventory
Compilation Sheet
Quartzville Administrative Unit

BLM-OSC Cooperative Project

Sample No.________ Plot________ Photo No.________ Date________

Land Form:
Slope (Percent)____________ Aspect (Bearing)____________

Slope Form: Concave ( ) Flat ( ) Convex ( )

Slope Position: Creekbottom ( ) Lower 1/3 ( ) Middle 1/3 ( ) Upper 1/3 ( ) Ridge Top ( )

Vegetation:
Timber species and % crown coverage____________________

____

Non-timber species and % coverage____________________

____

Site Index____________________________________

Soil:
Litter Depth______

A. Horizon Depth______ Texture______ Structure__________

Consistence______________ Color______________

B. Horizon Depth______ Texture______ Structure__________

Consistence______________ Color______________

C. Horizon Color______ Texture______ Structure__________

Kind of Parent Material______________ Drainage__________

Effective Depth (to rock or pan)____________________

Special Features____________________________________

Tentative Soil Series______________________________

Remarks:

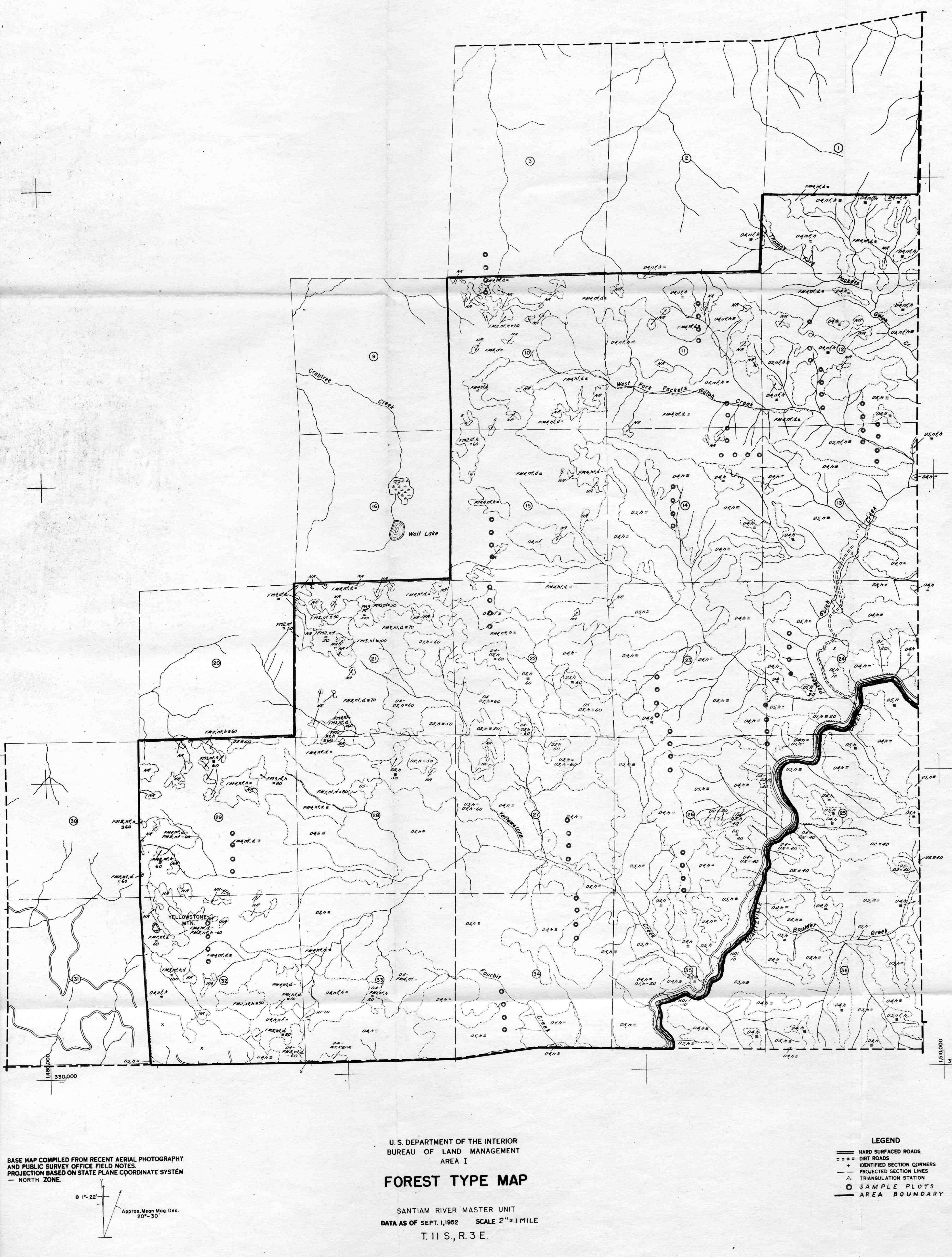
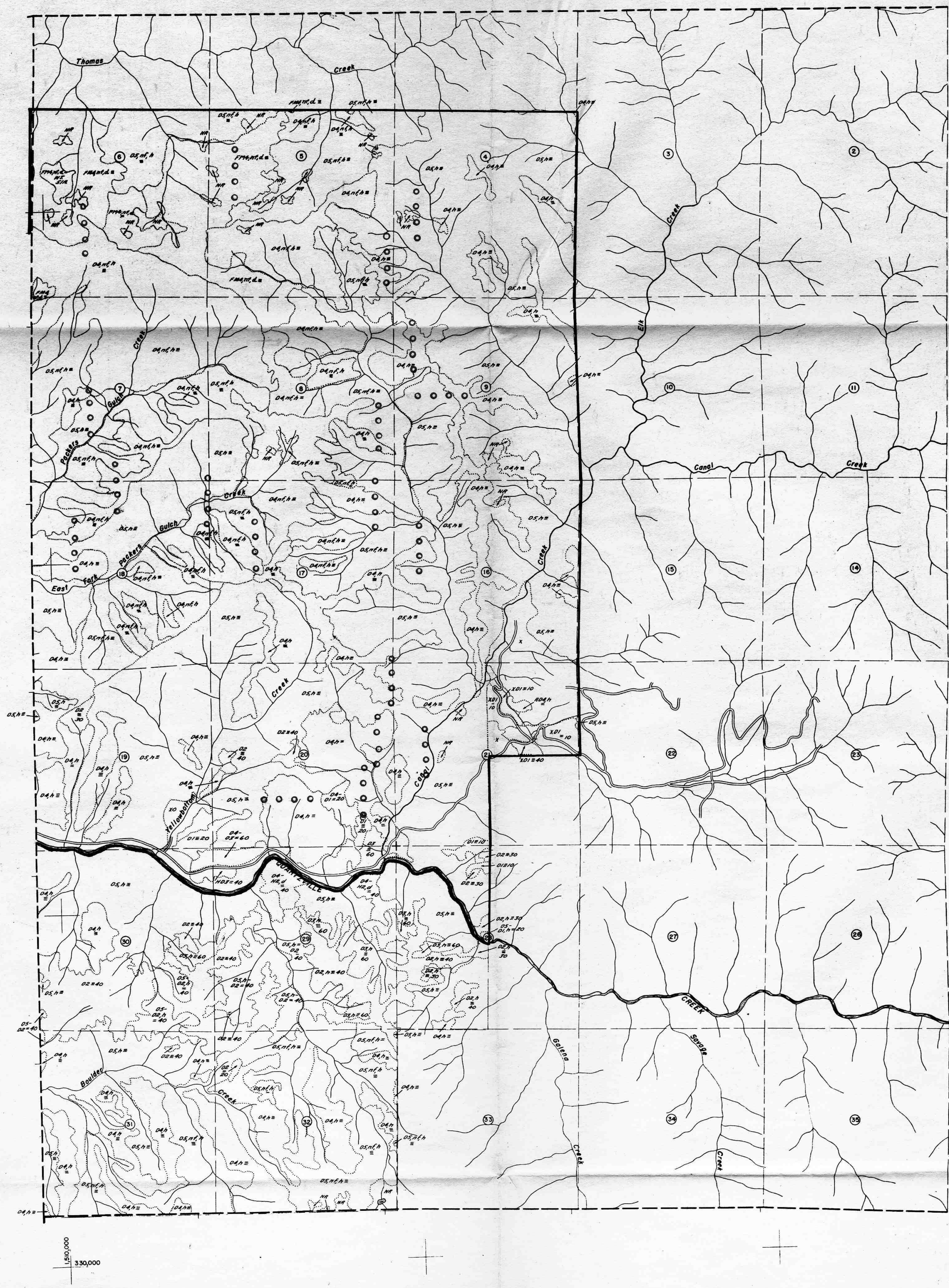
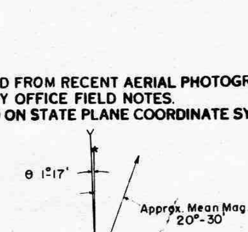


FIGURE 7. LOCATION OF RANDOM SAMPLE PLOTS, WEST HALF



BASE MAP COMPILED FROM RECENT AERIAL PHOTOGRAPHY AND PUBLIC SURVEY OFFICE FIELD NOTES.
PROJECTION BASED ON STATE PLANE COORDINATE SYSTEM — NORTH ZONE.



U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
AREA I

FOREST TYPE MAP

SANTIAM RIVER MASTER UNIT

DATA AS OF SEPT. 1, 1952 SCALE 2" = 1 MILE

T. 11 S., R. 4 E.

LEGEND

- HARD SURFACED ROADS
- DIRT ROADS
- PROJECTED SECTION LINES
- \+ IDENTIFIED SECTION CORNERS
- O SAMPLE PLOTS
- AREA BOUNDARY

QUART.
T. 11 S.

FIGURE 8. LOCATION OF RANDOM SAMPLE PLOTS, EAST HALF

TABLE III

DISTRIBUTION OF PLOTS BY LANDFORM
FACTORS TESTED AND SITE QUALITY

LANDFORM FACTORS	SITE QUALITY					
Degree of slope	I	II	III	IV	V	Total
gentle	0	3	5	6	2	16
medium	2	17	16	11	4	50
steep	1	14	35	32	6	88
precip.	0	0	3	2	1	6
Total	3	34	59	51	13	160

$\Sigma \chi^2 = 10.1913$ Critical value 5 per cent level = 21.0261, 12 degrees of freedom.

Aspect	I	II	III	IV	V	Total
north	1	9	12	6	2	30
south	0	11	26	22	3	62
east	1	8	16	18	3	46
west	1	6	5	5	5	22
Total	3	34	59	51	13	160

$\Sigma \chi^2 = 15.9180$ Critical value 5 per cent level = 21.0261, 12 degrees of freedom.

Slope form	I	II	III	IV	V	Total
concave	0	6	15	8	0	29
flat	3	17	37	30	9	96
convex	0	11	7	13	4	35
Total	3	34	59	51	13	160

$\Sigma \chi^2 = 12.2713$ Critical value 5 per cent level = 15.5073, 8 degrees of freedom.

III (CONTINUED)

LANDFORM FACTORS **SITE QUALITY**

Slope position	I	II	III	IV	V	Total
creek	0	4	2	1	0	7
lower	2	12	15	9	0	38
middle	1	15	23	17	2	58
upper	0	3	19	18	9	49
ridge	0	0	0	6	2	8
Total	3	34	59	51	13	160

$\Sigma \chi^2$ = 41.0351 Critical value 1 per cent level = 31.9999, 16 degrees of freedom.

Elevation	I	II	III	IV	V	Total
low	3	13	31	19	3	69
middle	0	17	20	25	7	69
high	0	4	8	7	3	22
Total	3	34	59	51	13	160

$\Sigma \chi^2$ = 10.1913 Critical value 5 per cent level = 15.5073, 8 degrees of freedom.

TABLE IV

DISTRIBUTION OF PLOTS BY VEGETATIVE FACTORS TESTED AND SITE QUALITY

VEGETATIVE FACTORS	SITE QUALITY					
Sword fern	I	II	III	IV	V	Total
0%	0	9	28	37	13	87
10	1	13	13	11	0	38
20	2	7	12	2	0	23
30	0	2	4	0	0	6
40	0	1	1	1	0	3
50	0	1	1	0	0	2
60	0	1	0	0	0	1
Total	3	34	59	51	13	160

$\Sigma \chi^2$ = 55.8195 Critical value 1 per cent level = 42.9798, 24 degrees of freedom.

Vine maple	I	II	III	IV	V	Total
0%	0	3	44	16	10	33
10	0	3	6	9	1	19
20	1	6	11	7	2	27
30	0	7	13	13	0	33
40	2	6	11	4	0	23
50	0	2	9	1	0	12
60	0	2	3	0	0	5
70	0	3	1	1	0	5
80	0	2	0	0	0	2
90	0	0	1	0	0	1
Total	3	34	59	51	13	160

$\Sigma \chi^2$ = 74.1310 Critical value 1 per cent level = 58.5700, 36 degrees of freedom.

Huckleberry	I	II	III	IV	V	Total
0%	2	10	32	23	4	71
10	0	12	15	20	4	51
20	1	9	9	4	5	28
30	0	1	2	4	0	7
40	0	1	1	0	0	2
50	0	1	0	0	0	1
Total	3	34	59	51	13	160

$\Sigma \chi^2$ = 22.4672 Critical value 5 per cent level = 31.4104, 20 degrees of freedom.

IV (CONTINUED)

VEGETATIVE FACTORS — SITE QUALITY

Rhododendron	I	II	III	IV	V	Total
0%	2	17	21	9	0	49
10	1	7	8	5	0	21
20	0	3	9	6	0	18
30	0	4	12	12	2	30
40	0	2	7	7	2	18
50	0	0	2	4	3	9
60	0	0	0	4	2	6
70	0	1	0	3	2	6
80	0	0	0	1	1	2
90	0	0	0	0	1	1
Total	3	34	59	51	13	160

ΣX^2 = 69.7136 Critical value 1 per cent level = 58.5700, 36 degrees of freedom.

Oregon grape	I	II	III	IV	V	Total
0%	0	14	15	13	8	50
10	0	9	23	18	4	54
20	2	4	13	15	1	35
30	0	4	6	4	0	14
40	0	2	2	0	0	4
60	1	1	0	1	0	3
Total	3	34	59	51	13	160

ΣX^2 = 38.9438 Critical value 1 per cent level = 37.5662, 20 degrees of freedom.

Bear grass	I	II	III	IV	V	Total
0%	3	26	37	10	1	77
10	0	6	17	29	5	57
20	0	2	5	11	5	23
30	0	0	0	1	1	2
40	0	0	0	0	1	1
Total	3	34	59	51	13	160

ΣX^2 = 62.1364 Critical value 1 per cent level = 31.9999, 16 degrees of freedom.

IV (CONTINUED)

VEGETATIVE FACTORS	SITE QUALITY					
Salal	I	II	III	IV	V	Total
0%	1	24	32	23	5	85
10	2	4	8	11	3	28
20	0	4	10	11	3	28
30	0	1	2	2	1	6
40	0	1	3	2	1	7
50	0	0	3	0	0	3
60	0	0	1	1	0	2
70	0	0	0	1	0	1
Total	3	34	59	51	13	160

Σx^2 = 20.9279 Critical value 5 per cent level = 41.3372, 28 degrees of freedom.

TABLE V

DISTRIBUTION OF PLOTS BY SOIL FACTORS TESTED AND SITE QUALITY

SOIL FACTORS — SITE QUALITY

Depth of A horizon	I	II	III	IV	V	Total
2"	0	0	0	0	3	3
4	0	9	10	10	2	31
6	2	14	26	23	5	70
8	0	9	14	10	2	35
10	1	2	8	6	1	18
12	0	0	1	1	0	2
14	0	0	0	1	0	1
Total	3	34	59	51	13	160

$\Sigma x^2 = 44.047$ Critical value 1 per cent level = 42.9798, 24 degrees of freedom.

Depth of A and B horizon	I	II	III	IV	V	Total
2"	0	0	0	0	1	1
4	0	0	2	2	0	4
6	0	0	1	4	1	6
8	0	0	2	1	0	3
10	0	0	1	1	0	2
12	0	2	3	1	0	6
14	0	3	4	3	4	14
16	1	5	8	4	0	18
18	1	4	9	13	4	31
20	0	8	3	9	1	21
22	0	6	7	4	1	18
24	0	3	9	5	1	18
26	0	1	1	2	0	4
28	0	1	4	0	0	5
30	1	1	3	1	0	6
32	0	0	2	1	0	3
Total	3	34	59	51	13	160

$\Sigma x^2 = 58.5796$ Critical value 5 per cent level = 79.0819, 60 degrees of freedom.

V (CONTINUED)

SOIL FACTORS — SITE QUALITY

Depth of B horizon	I	II	III	IV	V	Total
0"	0	0	6	9	2	17
6	0	1	0	0	0	1
8	0	3	5	1	1	10
10	1	3	12	6	3	25
12	1	11	11	17	3	43
14	0	5	4	10	2	21
16	0	7	4	2	2	15
18	0	1	5	2	0	8
20	1	1	7	3	0	12
22	0	2	3	1	0	6
26	0	0	1	0	0	1
28	0	0	1	0	0	1
Total	3	34	59	51	13	160

Σx^2 = 39.2242 Critical value 5 per cent level = 60.500, 44 degrees of freedom.

Texture of A horizon	I	II	III	IV	V	Total
light	0	1	3	4	0	8
medium	3	32	42	43	11	141
heavy	0	1	4	4	2	11
Total	3	34	59	51	13	160

Σx^2 = 10.8104 Critical value 5 per cent level = 15.5073, 8 degrees of freedom.

Texture of B horizon	I	II	III	IV	V	Total
no B	0	0	6	9	2	17
light	2	16	20	18	3	59
medium	1	16	27	16	7	67
heavy	0	2	6	8	1	17
Total	3	34	59	51	13	160

Σx^2 = 13.7680 Critical value 5 per cent level = 21.0261, 12 degrees of freedom.

V (CONTINUED)

SOIL FACTORS	SITE QUALITY					
Texture of C horizon	I	II	III	IV	V	Total
no texture recorded	0	0	0	0	1	1
light	3	25	42	31	8	109
medium	0	8	11	17	3	39
heavy	0	1	6	3	1	11
Total	3	34	59	51	13	160

Σx^2 = 17.7191 Critical value 5 per cent level = 21.0261, 12 degrees of freedom.

Structure of A horizon	I	II	III	IV	V	Total
very fine subangular blocky	2	27	49	47	13	138
fine subangular blocky	1	7	9	4	0	21
grandular	0	0	1	0	0	1
Total	3	34	59	51	13	160

Σx^2 = 8.5909 Critical value 5 per cent levels= 15.5073, 8 degrees of freedom.

Structure of B horizon	I	II	III	IV	V	Total
no B	0	0	6	9	2	17
very fine subangular blocky	2	13	35	32	10	92
fine subangular blocky	1	19	16	10	1	47
medium subangular blocky	0	2	2	0	0	4
Total	3	34	59	51	13	160

Σx^2 = 27.8923 Critical value 1 per cent level = 26.2170, 12 degrees of freedom.

V (CONTINUED)

SOIL FACTORS	SITE QUALITY					
Structure of C horizon	I	II	III	IV	V	Total
no structure recorded	0	0	1	0	1	2
very fine subangular blocky	2	28	49	45	9	133
fine sub-angular blocky	1	4	5	4	2	16
medium sub-angular blocky	0	2	4	2	1	9
Total	3	34	59	51	13	160

$\Sigma x^2 = 9.2557$ Critical value 5 per cent level = 21.0261, 12 degrees of freedom.

Consistence of A horizon	I	II	III	IV	V	Total
non-sticky	0	1	10	9	3	23
slightly sticky	2	26	45	37	10	120
sticky	1	7	4	5	0	17
Total	3	34	59	51	13	160

$\Sigma x^2 = 12.1348$ Critical value 5 per cent level = 15.5073, 8 degrees of freedom.

Consistence of B horizon	I	II	III	IV	V	Total
no B	0	0	6	9	2	17
non-sticky	0	0	3	2	2	7
slightly sticky	1	13	24	25	5	68
sticky	2	21	26	15	4	68
Total	3	34	59	51	13	160

$\Sigma x^2 = 20.9040$ Critical value 5 per cent level = 21.0261, 12 degrees of freedom.

V (CONTINUED)

SOIL FACTORS — SITE QUALITY

Rock in A horizon	I	II	III	IV	V	Total
no rock	1	11	24	20	8	64
1 - 24%	0	4	4	2	1	11
25 - 49	0	5	12	15	4	36
50 - 74	1	9	10	9	0	29
75+	1	5	9	5	0	20
Total	3	34	59	51	13	160

$\Sigma x^2 = 15.1444$ Critical value 5 per cent level = 26.2962, 16 degrees of freedom.

Rock in B horizon	I	II	III	IV	V	Total
no rock	2	16	28	25	5	76
1 - 24%	0	5	7	6	3	21
25 - 49	1	7	10	10	3	31
50 - 74	0	5	13	9	2	29
75+	0	1	1	1	0	3
Total	3	34	59	51	13	160

$\Sigma x^2 = 8.5756$ Critical value 5 per cent level = 26.2962, 16 degrees of freedom.

Rock in C horizon	I	II	III	IV	V	Total
no rock	3	16	23	18	7	67
1 - 24%	0	8	8	11	2	29
25 - 49	0	6	10	10	3	29
50 - 74	0	3	12	11	1	27
75+	0	1	6	1	0	8
Total	3	34	59	51	13	160

$\Sigma x^2 = 13.0740$ Critical value 5 per cent level = 26.2962, 16 degrees of freedom.

V (CONTINUED)

SOIL FACTORS — SITE QUALITY

Shot in A horizon	I	II	III	IV	V	Total
no shot	2	26	41	33	12	114
1 - 24%	0	1	5	5	1	12
25 - 49	0	3	7	10	0	20
50 - 74	1	2	5	2	0	10
75+	0	2	1	1	0	4
Total	3	34	59	51	13	160

Σx^2 = 15.5105 Critical value 5 per cent level = 26.9862, 16 degrees of freedom.

Shot in B horizon	I	II	III	IV	V	Total
no shot	2	28	43	41	13	127
1 - 24%	0	1	7	4	0	12
25 - 49	1	2	5	3	0	11
49 - 74	0	3	4	3	0	10
Total	3	34	59	51	13	160

Σx^2 = 10.6916 Critical value 5 per cent level = 21.0261, 12 degrees of freedom.

Shot in C horizon	I	II	III	IV	V	Total
no shot	3	34	54	41	12	144
1 - 24%	0	0	3	3	1	7
25 - 49	0	0	1	6	0	7
50 - 74	0	0	1	1	0	2
Total	3	34	59	51	13	160

Σx^2 = 13.6820 Critical value 5 per cent level = 21.0261, 12 degrees of freedom.