AN ABSTRACT OF THE THESIS OF

Ivars John Steinblums for the degree of Master of Science

in Forest Engineering (Hydrology) presented on June 22, 1977

Title: Streamside Buffer Strips: Survival, Effectiveness, and Design

Abstract approved: Redacted for privacy

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Stream buffer strips are an important tool for protecting the stream environment. This research documents the losses from 40 stream buffer strips, in the Western Cascades of Oregon, established 1 to 15 years before the study. Predictive equations are developed which identify the major reasons for buffer strip losses. Losses from wind, sunscald, logging damage, and other factors were estimated. The effectiveness of buffer strips for stream shading was quantified.

Wind is the major cause of stream buffer strip mortality. Damage from wind is often sudden, and catastrophic, while damage due to logging or disease and insects occurs at a slower rate. The average percent of standing timber remaining in the stream buffer strips sampled was 84 percent, ranging from 22 to 100 percent. Additional losses occured over the winter of 1975-1976, amounting to 5 percent of an initial sample of 34 buffer strips. A second set of 6 buffer strips suffered a 52 percent loss. The combined array of buffer strips lost 13 percent additional volume in this relatively mild winter.

Topography and uncut timber stand protection are the most important factors modifying the amount of windthrow in a buffer strip. The distance to the cutting line in the direction of damaging winds was the most important single variable influencing buffer strip survival, with increasing distances leading to significantly poorer survival. Two other significant protection factors were the distance and change in elevation from the buffer strip to the nearest major ridge in the direction of damaging winds. Nearby ridges and steeper slopes give better protection.

Timber factors also influence stream buffer strip survival. Increasing values for the following timber factors are associated with significantly poorer survival: average stand height, average height of trees taller than 100 feet, number of trees per acre taller than 160 feet, original timber volume per acre, original basal area per acre, and average volume per tree. Western red cedar (Thuja plicata) was the most windfirm tree species, followed by western hemlock (Tsuga heterophylla), Douglas-fir (Pseudotsuga menziesii), and true fir (Abies spp.), in decreasing order of windfirmness. Species tolerance to wet sites, plus the timber factors described above, may help explain the windfirmness ranking.

Wet sites increase a tree's susceptibility to windthrow. Water table measurements in two buffer strips with windthrow indicated that the water table rose high enough to reach a tree's rooting zone, while the water table in a buffer strip without windthrow did not enter the root zone. Water tables within a tree's rooting zone may result in poorer rooting and tree anchorage

The above factors, combined in multiple regression equations developed in this study, account for approximately 68 to 95 percent of the variation in predicting buffer strip survival.

Measured buffer strip shading shows that a buffer strip 85 feet wide shades a stream as well as an average undisturbed canopy, while 75 percent of the undisturbed canopy shading can be achieved with a buffer strip 52 feet wide. Width alone is not adequate for buffer strip design as topographic, timber stand, and understory factors greatly influence stream shading.

Windthrow in stream buffer strips poses a difficult salvage problem, and may also damage the stream environment. Therefore, on sites very susceptible to windthrow, the best stream protection alternative may be to carefully remove the streamside trees with directional falling methods.

Streamside Buffer Strips: Survival, Effectiveness, and Design

by

Ivars John Steinblums

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

completed August 5, 1977

Commencement June 1978

APPROVED:

Redacted for privacy

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Date thesis is presented June 22, 1977

Typed by Maja Laird for Ivars John Steinblums

ACKNOWLEDGEMENTS

This study was financially supported by a steady flow of MacIntire-Stennis and Oregon State University Forest Research Laboratory funds. Many individuals gave freely of their time to make the completion of this thesis a reality. I would especially like to thank Dr. Henry Froehlich for his continued advice and editorial assistance throughout this study. Additional thanks are extended to Dr. Larry Boersma and Dr. Robert Beschta for their careful review of this thesis and words of encouragement. Special thanks go to Scott Hess for his many hours of help in the field. Finally, considerable help was steadily forthcoming from the individuals listed below, who provided much of the direction and information that was necessary to complete this thesis.

Thesis review: Dr. Henry Froehlich, Dr. John Potter, Dr. Larry Boersma, Dr. Robert Beschta

O.S.U. School of Forestry: Dr. Bill Emmingham, Dr. Dennis Dykstra, Dr. James Krygier, Dr. Carl Yee, Dr. Richard Waring, Dr. George Brown

Field Assistance: Scott Hess, Jim Haggenjos

O.S.U. Forest Research Laboratory Shop and Store Room: Jack Aldahl, Rex Davis, A.H. (Bud) Rieg, Arthur Hawks, Lawrence Johnston, J. Hartwig

U.S. Forest Service

PNW Forest and Range Experiment Station: Fred Swanson, Dr. Earl Nelson, Dr. Don Minore, George Harvey, Dr. Dennis Harr, Melvin Metcalf

Blue River Ranger District: Mel Wetteland, Lanny Elfring, Brad Leavitt

Columbia Gorge District: Dave Kiser, Gary Cook

Detroit District: Roger Penrose

Estacada Ranger District: Mike Strange, Carson Hall

Lowell Ranger District: Don Gray

McKenzie Bridge Ranger District: Len Farr, Jim Golden, Jim O'Brien

Oak Ridge Ranger District: Walt Parker

Rigdon Ranger District: Jack Watson

Sweet Home Ranger District: Dave Zimmerman, Gene Eide

Willamette National Forest S.O.: Eric Sieverts, Harold Legard

Mount Hood National Forest S.O.: Jack Parcell

Bureau of Land Management

Roseburg District: Don Kobelin, Dick Popp, Steve Wert, Frank Oliver

Eugene District: George Chalfant, Bob Van Sickler

Bohemia Lumber Company (Culp Creek): Mike Hogan

Typing: Maja Laird

Printing: Type Ink, Kinko's Copy Shop

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INTRODUCTION

Streamside buffer strips are one of several methods that can be used to protect the stream environment during and after timber harvesting. California, Oregon, and Washington all have a buffer strip clause in their forest practice rules.

Common reasons for leaving buffer strips are:

1. shade - keep stream temperature increases to a minimum.
2. debris barrier - create a barrier to logging debris that may possibly enter the stream channel.
3. sediment traps - slow down and trap material being eroded from exposed soil surfaces.
4. bank stabilization - act as a source of living roots which will help stabilize the stream bank.

Buffer strips do not always serve as well as they are intended. These leave strips, often blowdown, and load a stream channel with debris, thus diverting stream flow against exposed stream banks. Bank erosion then occurs and more trees may fall as a result. Rootwads of wind-thrown trees may be the source of additional sediments that reach the stream channel. Sediments originating from rootwads and stream bank erosion can degrade valuable fish spawning gravel. In extreme cases, debris from windthrow can block anadromous fish runs. During high flows, debris jams may fail and damage stream bed and banks, and man-made works such as bridges and camp-grounds. In addition, large timber values are lost when a buffer strip fails.

Observations indicate that, too frequently, buffer strips may not achieve their intended goals. There is a need to identify areas in which buffer strips should and should not be used. No study in the Western Cascades of Oregon has evaluated buffer strip survival, effectiveness, and design requirements. It is necessary to gain a better understanding of buffer strip survival in order to achieve a satisfactory level of stream protection.

OBJECTIVES AND SCOPE

The main objective of this study was to develop a guide to designing stream buffer strips with the greatest probability of survival. To achieve this objective, this study documented the survival of stream buffer strips left from 1 to 15 years ago, and identified the topography, site, and timber factors associated with stable and unstable buffer strips.

Two secondary objectives were to estimate the value of standing, windthrown, and dead timber in the stream buffer strips observed in this study, and to measure the effectiveness of stream buffer strips for stream shading.

The study was confined to a sample of stream buffer strips in the Western Cascades of Oregon. A variety of topographic, timber, and stream conditions were included in the sample.

LITERATURE REVIEW

Recently, many individuals have studied the effect of timber harvesting on the stream environment. Indeed, these studies have been diverse, but they all focus on lessening man's impact on the stream environment. While this study will investigate stream buffer strip survival, it will be helpful to review related work by other researchers and scientists.

Small Stream Processes

In order to design effective stream buffer strips, it is helpful to understand some principles of stream ecology. Small, forested streams are heterotrophic, that is, they receive most of their food energy from the land. The surrounding ecosystem constantly delivers organic matter, products of landscape weathering, and the very water which runs down the stream channel (Vannote, 1975).

Small consumers of various kinds use the organic material as their energy supply. Tiny stream invertebrates have evolved to process wood and leaves deposited by the forest. A host of bacteria and fungi aid the invertebrates as they process organic debris (Sedell and Triska, 1977).

The River Continuum

Mountain streams are not isolated individual units, but are an integral part of a large continuum, from the smallest intermittent stream to the largest river (Vannote, 1975). Therefore, it is necessary to respect even small channels that transmit water only a few days out of the year. Sound timber harvesting practices, such as directional falling or stream buffer strips, can help maintain the stability of small streams.

Man derives many benefits from a healthy river continuum, especially in the Pacific Northwest. Domestic water supplies and valuable fisheries resources are among the values provided to us by the stream systems.

Sediment in the Stream System

Excess sediment in the stream system can harm productive fish spawning gravel. Porous gravels are a prerequisite for the health and survival of salmonid alevins and fry. Even moderate increases in sediment levels in stream gravel can harm the condition of eggs and hatching fish (Cooper, 1965). Stream gravel plugged with sediment reduces the dissolved oxygen flow to fish eggs, and makes it extremely difficult for fry to emerge once they hatch (Moring and Lantz, 1974).

Commonly, stream buffer strips are thought of as being efficient "sediment traps". This theory assumes that flow through harvesting units is generally sheet flow. However, overland flow is rare in the forested watersheds of the Pacific Northwest, with channel flow predominating (Brown, 1974). This is mainly due to the high infiltration rate of the soil. Furthermore, Brown states that eroded material carried down in channels flows right through the buffer strip. Since buffer strips do not efficiently trap sediment, land managers must rely on other modern forestry practices to minimize sediment production.

Nature annually deposits millions of tons of sediment into the stream systems of the United States (Froehlich, 1976). Land management activities are also the source of stream sediments. Heavy rains and steep slopes, in untouched areas, are often the source of large debris avalanches or slides. Ketcheson (1977) is currently documenting natural debris avalanches in the steep headwall areas of the Siuslaw National Forest. It is virtually impossible to identify the source of sediments once they have reached the stream.

Road construction is the main source of sediment resulting from man's activity on forest land. The clear-cutting practice itself is usually a minor sediment producer. By combining a carefully chosen harvesting system with a well designed road system, sediment production can be held to acceptable levels on most sites. Generally, the harvesting system requiring the least road mileage will result in the least impact (Brown, 1974).

As described above, minimizing sediment production on commercially managed land can be accomplished by reducing road mileage. Many road related failures in the H.J. Andrews Experimental Forest, east of Eugene, Oregon, were related to failure of the road drainage system (Rothacher, 1968). Therefore, special attention should be given to road drainage maintenance and design. The mass soil movements, whether natural or man-caused, also deliver a large amount of organic debris to the stream system.

Stream Temperature and Fisheries

The most common reason for providing stream buffer strips is to shade a stream after timber harvesting. Buffer strips can be a valuable tool for keeping stream temperatures near normal. This is vital in streams inhabited by various species of resident trout or anadromous fish. Principles of buffer strip design for stream temperature must be coupled with an understanding of the fisheries resource to be protected.

Fish are sensitive to large increases in stream temperature for several reasons. Salmon and trout are cold water creatures, and assume a body temperature equal to that of their environment (Lantz, 1971). Elevated water temperatures may create a habitat favorable for fish pathogens, and increased populations of aquatic bacteria can cause death in fish (Brett, 1956).

Several studies have used constant temperature laboratory techniques to determine maximum temperature tolerance limits for fish. Coho salmon could not tolerate prolonged temperatures of greater than 77°F in a laboratory study using constant temperatures (Brett, 1952). However, water temperatures in streams rise gradually during the day, giving exposed fish time to become acclimated to the increasing temperatures. Brown (1972) observed that, in stream conditions, there was no mortality in coho salmon exposed to temperatures as high as 85°F for 8 hours.

The amount of dissolved oxygen stream water can hold decreases as stream temperatures increase. When stream temperatures increase from 57°F to 85°F, the saturation of dissolved oxygen concentration in stream water drops from 10.26 parts per million (ppm) to 7.44 ppm (Brown, 1973).

Effects of Timber Harvesting on Stream Temperatures

Streams may be shaded by topography, hardwoods, brush, commercial timber, and even stream debris. If most shade is cast by commercial trees, their removal will allow water temperatures to rise. Several studies have attempted to evaluate the impact of timber harvesting on stream temperatures. Brown (1967, 1970) developed an equation which allows prediction of potential stream temperature increases following clearcut logging. Application of the equation should be restricted to a stream reach of less than 2000 feet. When cooling groundwater enters the stream, a weighting component is utilized in the computations.

Brown and Krygier (1967) reported a maximum temperature increase of 28°F on a fully exposed clearcut watershed. Within several years, a dense strip of red alder (*Alnus rubra*) grew up near the stream and temperatures began to return to prelogging levels. Natural stream cover regrowth rates vary considerably, and are poorly understood.

Effects of Natural Events on Stream Temperature

Damaging flood and fire events periodically completely expose a stream, resulting in stream temperature increases. During the 1964 flood, 1300 feet of a small tributary to Lookout Creek in the H.J. Andrews Experimental Forest were scoured to bedrock. As a direct result, there was an increase in mean monthly water temperatures of from 7°F to 12°F between April and August (Levno and Rothacher, 1967). In a similar study in Washington, a 10°F maximum temperature increase was reported, during midsummer, in a burned watershed (Helvey, 1972).

Buffer Strip Design for Temperature

A well designed buffer strip can economically and effectively shade a stream, while keeping stream temperatures within acceptable limits. However, a buffer strip that has not been designed may shade the stream very little, needlessly tying up valuable timber.

Brazier and Brown (1973) investigated the characteristics of buffer strips important in regulating temperatures in small streams. They found that maximum stream shading occurs within a buffer strip width of 80 feet. Moreover, they state that commercial timber volume and buffer strip width alone do not determine the shading ability of a buffer strip. "The canopy density along the path of incoming solar radiation best describes the ability of the buffer to control stream temperature" (Brazier and Brown, 1973; p. 1). Measurements made with an angular canopy densiometer provide a means of directly measuring the ability of a buffer strip to control stream temperature (Brazier, 1973).

The conditions affecting potential stream temperature increases at each stream are different, so buffer strip design must be done site by site (Brazier, 1973). Variables he found which affect potential temperature increases are the following: stream width, stream depth, solar angle, topography, and characteristics of the riparian vegetation. All of the factors listed above should be considered in the design of a buffer strip for temperature control.

Brown (1975) identifies situations in which buffer strips are effective for stream temperature control and where they are not. Only trees left on the south bank of an east-west flowing stream block the sun at the most critical time. The trees on the north side of an east-west flowing stream serve no purpose for temperature control. He concludes by saying it is important to consider all options when laying out a buffer strip; because brush shade, conifer shade, and hardwood shade are equally effective.

There are very few written guides that describe buffer strip design for temperature control. One of the best guides has been compiled by the Pacific Northwest Forest and Range Experiment Station (U.S.D.A., 1974). Two objectives are stressed: to provide a means of predicting stream temperature changes after timber harvesting, and to give a land manager factors to consider when designing a buffer strip for stream temperature control.

Buffer Strips as Debris Barriers

Buffer strips are recognized as being effective for keeping logging debris out of streams, particularly on steeper slopes (Froehlich, 1975B). Buffer strips have effectively blocked debris even when they were narrow and not continuous (Froehlich, 1973).

In a recent study, McGreer (1975) found that buffer strips kept most debris from entering the stream. Only 1.8 and 2.0 tons of debris per 100 feet of stream channel penetrated buffer strips of 36 and 15 foot widths, respectively. To get a perspective on the debris levels outlined above, it is important to recall the work of Lammel (1972) and Froehlich (1973), in which they found debris loadings of 6 1/2 to 26 tons per 100 feet of undisturbed stream channel.

Stream Debris

Stream debris has been the subject of considerable controversy in recent years. An understanding of stream debris sources, quantities, and implications will aid a land manager in choosing the best stream protection alternative for a given site.

Under natural conditions, organic material enters the stream channel by lateral movement, litterfall, and the blowdown of trees or branches (Sedell and Triska, 1975). Natural mortality is also a continuous source of debris. Slash from timber harvesting is another source of stream debris.

As stated earlier, organic material from the land is the major source of food energy for stream organisms. Additionally, large organic debris retains smaller material so it can be processed by the various stream microorganisms and invertebrates (Sedell and Triska, 1975). Without such a retention mechanism, small organic materials would be flushed, unprocessed, out of small headwater streams.

Large organic debris in streams controls channel morphology (Swanson and Lienkaemper, 1976). In small channels, large debris acts as an energy dissipator. Random deposition of large organic debris forms low gradient sections separated by falls. These low gradient sections are formed slowly, as sediment and gravels are trapped behind debris. Small falls formed by debris consume considerable energy, thereby reducing the erosive force of water (Heede, 1972).

Swanson and Lienkaemper (1977) summarize the advantages of large debris energy dissipators. They list the following benefits: a decrease in erosion of stream bed and banks, more sediment storage, slower movement of organic material, and a more diverse habitat for riparian organisms. Furthermore, they suggest that natural accumulations of debris remain in the stream channel for a period of time ranging from decades to over a century.

Larger debris accumulations in small streams can be hazardous. Debris accumulates when small headwater streams are unable to float away material larger than branchwood or small pieces of broken logs. Often a debris avalanche moves the material downstream into a higher order stream (Froehlich, 1975A). Debris torrents frequently scour the stream bottom to bedrock, leaving the stream bottom temporarily void of valuable spawning gravel. Frequently, road failures can be traced to culverts plugged with debris (Rothacher, 1968).

Small organic debris, especially leaves, needles and fine branches serve as food for microorganisms (Brown, 1973). Furthermore, simple sugars, leached from fine organic material, are degraded by microorganisms and used as an energy source. Microbial decomposition of this fine organic material uses oxygen and can lower the dissolved oxygen concentration in stream water. Fish become endangered when dissolved oxygen concentrations drop below 4-5 milligrams per liter (mg/l). Summer months are the most critical period of time when a deposit of fine organic material has the greatest effect on dissolved oxygen levels. Low flow, and high stream temperatures, combined with the high oxygen demand exerted by fine debris, can drop dissolved oxygen to dangerously low levels (Ponce and Brown, 1974). Fortunately, natural stream reaeration processes are continually at work and in most cases keep the dissolved oxygen concentration at a safe level.

Alternate Stream Protection Methods

All stream protection alternatives should be carefully weighed before a harvesting system is selected. Besides buffer strips, there are three other methods for keeping logging debris out of streams: hydraulic jacking, cable-assisted falling, and leaving high stumps above the stream (Brown and Ponce, 1974).

Lammel (1972) and Froehlich (1973) reported cable-assist falling minimized breakage, and allowed for cleaner yarding than with conventional falling alone. McGreer

(1975) continued their work and compared the costs and impacts to the stream environment associated with conventional falling to two other stream protection alternatives: uphill cable-assist timber falling and conventional falling with a buffer strip. He observed that cable-assist falling added only 30 percent of the amount of debris to the stream that was added by conventional falling. Cable-assist falling also reduced breakage by 1.4 percent, and produced more logs of desired lengths. As described earlier, buffer strips kept most debris out of the stream. Finally, he advises that cable-assist falling has distinct advantages in the following conditions: steep slopes, rough ground, sensitive streams, and in timber stands with large or defective trees.

Directional falling with hydraulic jacks is another effective method that can be used to keep debris out of the stream. Trees with up to 20-30 feet of backlean or 12-25 feet of sidelean can be felled uphill using hydraulic jacks. For an average stand of old growth Douglas-fir in southwestern Oregon, controlled falling increased volume recovery a minimum of 10 percent, but decreased a faller's productivity by up to 40 percent. Fortunately, the gain in volume recovery more than offsets any loss in falling productivity (Groben, 1976). Additionally, he lists many advantages to using controlled falling methods. They are:

1. increased yarding and loading productivity,
2. less stream clearance,
3. increased productivity and grade recovery at the mill,
4. increased safety for fallers,
5. improved appearance of clearcut.

Froehlich and Dykstra (1976) examined the costs associated with the following stream protection methods: conventional falling, cable-assist falling, and buffer strips with conventional falling. They found that none of the three methods is clearly the best in the majority of study areas. In 4 out of 10 areas, the least cost stream protection alternative was a buffer strip 55 feet in width. Conventional and cable-assist falling were each the least cost alternative on 3 out of 10 areas. In conclusion, they explain that a decision on which stream protection methods to use cannot be made solely on a cost analysis basis.

Timber Harvesting Near Buffer Strips

The presence of a buffer strip often adds to the complexity of skyline logging. Buffer strips can become "rigging nightmares" for loggers who must work near them. Often, in order to secure a tailhold, trees in a buffer strip have to be removed to make way for a skyline corridor. Multi-span skylines may be an alternative to the complexities of rigging through a buffer strip (Aulerich, 1977). McGreer (1975) adds three other factors that are associated with logging near buffer strips:

1. less favorable landing placement
2. more road mileage
3. increases in time required for line moving.

Factors Contributing to Buffer Strip Mortality

Blowdown, sunscald, and logging damage are the three main factors contributing to buffer strip mortality

(Froehlich, 1975B). At this time, it appears that blowdown accounts for the largest share of buffer strip mortality.

Logging Damage

Even though early observations indicated that logging damage has not caused significant buffer strip mortality, it may be a factor to consider if the buffer strip is expected to stand for many years. The long term effect of logging damage on buffer strip survival has gone largely unquantified, as it requires the careful observation of a buffer strip for a number of years. Intuitively, damage to the trees in a buffer strip should increase the likelihood of future mortality.

Shea (1961, 1967) studied the effect of logging injury on second growth Douglas-fir and western hemlock. His studies show that Douglas-fir is more resistant to decay due to logging injuries than is western hemlock. Bole injuries may allow the entry of molds and fungi.

> "Even slight injuries from logging permit decay or root rot fungi to enter the roots and eventually destroy them, as a result both windthrow and butt rot are more likely to occur" (Shea, 1967; p. 8)

Windthrow

Windthrow in stream buffer strips and along cutting lines is a problem that has been perplexing forest managers for many years. Wind causes damage to forest trees in two ways: windsnap and windthrow. Windsnap is defined as stem failure, and windthrow as rooting system failure. These problems are worldwide in forestry (Mayhead, 1972). It is important to realize that windthrow is a natural forest process (Stephens, 1956). Windthrow upturns the forest soil in a manner which is similar to plowing by a farmer (Lutz, 1940).

Nearly 20 years ago, Loucks (1957) investigated windthrow in the lakeshore reservations of Pine Quetico Provincial Park, Ontario, Canada. His results indicated that mortality from causes other than wind was the same in the shore reservations as it was in the control. Wind damage was found to be localized in occurrence. In addition, some of the shore reservation blowdown was associated with poorly drained soils and trees with trunk rot. In conclusion, he states it is possible that characteristics associated with areas prone to blowdown can be identified, and damage be avoided in the future.

Buffer strips in Alaska often suffer blowdown losses. Gale force winds and intense rains combine and make blowdown problems inevitable. Since the risk of blowdown is great, timber stands are logged to the stream bank, or are not harvested at all (Baugh, 1975).

Moore and McDonald (1974) are currently studying buffer strip survival on Vancouver Island, British Columbia. They have described widespread blowdown problems and are trying to relate them to wind, rainfall, soil type, soil drainage, and plant indicators.

Storm winds in the Western Cascades generally come from the southwest, and less frequently from the east. In a windthrow study done in the Western Cascades at the H.J. Andrews Experimental Forest, the average direction of fall for windthrown trees was N 33° E (Gratkowski, 1956).

Winds from the southwest are usually in the form of large oceanic frontal storms. Air masses stagnating over the great basin in the western United States occasionally give rise to strong Foehn winds traveling westward over the Western Cascades. The Foehns may closely follow the land profile, from the highest crest to the sea and may be miles wide or very narrow (Buck, 1964).

Local topography has a strong influence on the amount of windthrow at a cutting boundary or buffer strip. The extent of wind damage is moderated by the location of the cutting line or buffer strip with respect to the local topography. Wind damage is heaviest on cutting boundaries located on the lee side of a ridge in the Coast range and Western Cascades (Ruth and Yoder, 1953; Gratkowski, 1956). Especially, north and east cutting boundaries on the lee side of ridges are extremely susceptible to southwest winds (Ruth and Yoder, 1953). Western cut boundaries on the lee side of ridges are very exposed to the less frequent winds coming from the east. Cutting boundaries along creeks are the least wind resistant of all (Gratkowski, 1956).

Wind movement over ridges and through saddles is complex and difficult to interpret. Wind speeds generally increase as an air mass moves over a ridge. Wind passing through saddles increases in velocity because the air is forced to flow through a narrower passageway (Gratkowski, 1956). The result of wind constriction by a saddle is usually heavy damage on the opposite side of the ridge (Ruth and Yoder, 1953).

Steep topography usually gives protection to the trees in a buffer strip. However, roll eddies and turbulence are common beneath plateau rims and canyon walls, and on the lee side of ridges that break off abruptly. Actually, roll eddies are winds opposite in direction to the winds flowing over a ridge (Buck, 1964).

Lee flow, or downslope winds, cause minor damage on slopes greater than 70 percent. This is because winds generally do not adhere to these extremely steep slopes

(Ruth and Yoder, 1953). Lee flow most often occurs when wind velocities are up to 40-50 mph and slopes are less than 70 percent (Manley, 1945). Winds generally follow valleys. Moreover, V or egg shaped indentations in the stand may channel winds, thus causing considerable damage (Curtix, 1943).

The characteristics of the original timber stand markedly influence the windfirmness of individual trees. Trees grown in dense stands are sheltered, and are not exposed to strong winds. Thus, cutting in a dense stand leaves the remaining trees exposed, and in danger of being windthrown (Gratkowski, 1956).

Trees that are exposed to wind during growth generally develop windfirmness. Exposure to wind triggers growth responses within the trees which allow them to become increasingly windfirm. Trees in open stands allocate their yearly growth potential towards developing strengthening tissues in their roots and base (Mergen, 1954). More specifically, the tissue strengthening occurs on the lee side of the tree (Ruth and Yoder, 1953; Carlton, 1976).

Strong, horizontal, "bracket-angle" type roots on the leeward side of the tree are the main supporting roots during a windstorm. Characteristically, these roots are short and stout. During severe winds, the roots on the leeward side of the tree are subject to compressive forces which, if strong enough, cause the roots to break. Sinker roots or large stones under the bracket-angle type roots sometimes add a measure of wind resistance (Mergen, 1954).

Root development on steep topography increases the uncertainty in determining the windfirmness of an individual tree. Tree roots on steep ground spread downhill, acting somewhat like a buttress. Roots on the uphill side of a tree are shorter, and much less developed (Steinbrenner and Gessel, 1956).

The rooting characteristics of each tree species are different, making certain trees more susceptible to windthrow than others. Steinbrenner and Gessel (1956) studied the roots of windthrown trees on the McDonald Tree Farm in southwestern Washington. Douglas-fir, depending on the soil type, developed a heavy, extensive root system with main anchor roots up to 16 inches in diameter. Douglas-fir had a more developed root system than western hemlock or western red cedar. The larger roots of western hemlock were composed of grafts of smaller roots. Western red cedar had the least developed root system, mainly composed of small, stringy roots.

Root growth is strongly affected by ease of root penetration, soil aeration, and the moisture holding capacity of the soil. Well aerated sandy soils give rise to deep, spreading root systems, while root systems in dry clayey soils are shallower and not as widespread (Mergen, 1954).

Rooting depth is very important in determining a tree's resistance to strong winds. Small increases in rooting depth can significantly increase a tree's resistance to wind (Fraser, 1962). The physical condition of the soil can be a major factor in determining root development. Soil influences a tree's windfirmness in two main ways. To begin with, root distribution is affected by soil texture, while soil consistency governs the degree of anchoring provided by the roots. Soil depth can determine whether a tree is deeply or shallowly rooted (Mergen, 1954). Very dense soil layers or solid rock effectively restrict rooting (Steinbrenner and Gessel, 1956). "While deep rooting is characteristic of Douglas-fir, rooting depth is necessarily limited by soil depth" (McMinn, 1962; p. 119).

"Trees growing on wet, poorly drained sites are very vulnerable to windthrow, and have flat plate-like root systems" (Gratkowski, 1956; p. 69). A high water table can restrict root development, not unlike a dense soil or rock layer. Basically, waterlogged soil restricts aeration. Roots grown under poorly aerated conditions are short, stubby and near the surface (Taylor, 1972). In addition, wet soils provide a poor anchoring medium for roots (Gratkowski, 1956).

> "Sandy and clayey soils have consistencies very much dependent on water content. Non-cohesive materials, such as dry sands, anchor trees through frictional forces only and these sandy soils are most resistant when their moisture content is at or close to field capacity. Clay soils in contrast to sandy soils, exhibit their greatest cohesion when dry" (Mergen, 1954; p. 124).

Tree species are often found on a wide variety of sites, but make their best growth only under certain conditions. Douglas-fir grows best on deep, loamy, well drained porous soils (Harlow and Harrar, 1969). Fowells (1965) notes that Douglas-fir will not grow well on poorly drained sites or soils with a restricting layer. Western hemlock grows best on moist porous soils and develops a shallow, wide-spreading root system (Harlow and Harrar, 1969). Western red cedar grows best on wetter flats and slopes. On drier sites, western red cedar is relatively windfirm, while on wetter sites it is shallowly rooted (Fowells, 1965).

The physical characteristics of an individual tree are very important in determining actual wind resistance. Winds blowing against an exposed tree crown produce a bending force which acts at a point approximately 1/3 of the distance from the base of the crown to the top of the tree. Curtis (1943) named this spot in the crown the form point. If all other factors are equal, the height of the form point and type of crown are most important in judging a tree's stability in strong winds. Open crowned trees with low form points offer less resistance to the wind and seem more stable. Old, dense even aged stands with shallow rooting and a high form point are very susceptible to windthrow (Curtis, 1943).

Windfirm trees have generally grown in open stands, have good root systems and tapered, stocky stems. In fact, windfirm trees have large, live crown ratios and wide, deep crowns (Smith, 1962).

The tip of an exposed tree oscillates back and forth when exposed to winds. Additionally, the windward and leeward sides of the tree are alternately exposed to compressive and tensile stresses. Failure in the wood occurs mostly during compression. Compression failures in cell walls are most likely to take place near the ground. Succeeding winds may induce additional compression failures until the tree can no longer support its own weight (Mergen, 1954).

Several studies have rated the windfirmness of individual tree species. Douglas-fir was the most windfirm tree species in southwestern Washington, followed by western hemlock, and western red cedar (Steinbrenner and Gessel, 1956). Another study, in the Coast Range of Oregon, found Douglas-fir and sitka spruce (Picea sitchensis) were more windfirm than western hemlock (Ruth and Yoder, 1953). At the H.J. Andrews Experimental Forest, Gratkowski (1956) observed that western red cedar was least susceptible to windthrow, especially where it was growing on drier sites, and had an open crown with a stout-tapered bole. Hardwoods withstood twice as much bending force as white pine (Pinus strobus), probably because they were open crowned and had better root systems (Curtis, 1943).

Windthrow risk in residual stands increases with greater canopy irregularity (Bradley, 1969). Furthermore, isolated trees, holes, or strips located within the residual stand lead to a greater windthrow risk. Timber stands become more subject to windthrow as they become taller and older (Persson, 1969)

Root and stem rots render a tree very vulnerable to windsnap or windthrow (Ruth and Yoder, 1953). Root rots accounted for 34 percent of the windthrow in Douglas-fir in a study completed at the H.J. Andrews Experimental Forest. Twenty percent of the windthrown Douglas-fir were infected with some species of butt rot (Gratkowski, 1956).

Implications of Buffer Strip Failure

Several potential problems are created when a buffer strip fails. Besides the monetary value lost in windthrown buffer strip, there are several more intangible losses as well. As mentioned earlier, stream debris from a windthrown buffer strip can contribute to a debris torrent or divert the erosive force of water against a stream bank. Sediments washed out of the rootwads of windthrown trees can plug porous spawning gravels or increase the turbidity in a municipal water supply.

Windthrown trees in a buffer strip can serve as breeding place for beetles, thereby creating a hazard for the trees in the immediate vicinity. Johnson, et. al. (1959) studied beetle infestation in Douglas-fir trees windthrown during a storm in November, 1958. They found that beetles emerging from windthrown trees pose a threat to green timber. Beetle attacks decrease with distance from the down material. Beetles seem to attack all trees in the immediate vicinity of windthrow (Johnson and Pettinger, 1961). In conclusion, they state it is important to remove windthrow in the spring and early summer before it becomes infested with bark beetles.

Stream cleanup and salvage are often difficult, if not impossible, when a buffer strip fails in rough topography (Froehlich, 1975B). The distance from the buffer strip to the nearest landing is often great, and equipment capable of yarding logs over long distances must be moved in. Yarding costs in such a situation are likely to be very high.

Difficult access to buffer strips is, for the most part, the rule rather than the exception. Therefore, buffer strips must be designed for long term survival. Care should be taken during planning to investigate the feasibility of salvage and stream cleanup in case of buffer strip failure. Cable-assist falling can be used to good advantage as a stream protection measure in areas of high buffer strip blowdown potential, or where the timber resource itself is critically important (McGreer, 1975). Limiting the amount of stream exposed at any one time will aid in keeping stream temperature increases within acceptable limits.

Harvesting a windthrown buffer strip is difficult, often being more hazardous and less productive than in a normal unit. Bucking windthrown trees may be dangerous for the bucker.

There are no known studies of logging costs for a windthrown buffer strip. However, in a study of logging costs on a windthrown unit, yarding output was 26 percent less than in a similar area without blowdown. The decrease in yarding output was probably due to delays in yarding through slash, high stumps, and root wads (Binckley, 1964).

Buffer Strip Design for Survival

Identifying an area prone to wind damage, prior to timber harvesting activities, is the key to keeping windthrow losses to a minimum. Careful observation of local topography can give important clues as to the potential success of a cutting boundary or stream buffer strip. "... regardless of how stands are cut or the soil and stand conditions, the risk of blowdown is greater on some exposures than others" (Alexander, 1972).

A knowledge of the prevailing wind direction is an absolutely essential part of locating stable cutting boundaries. Studying the general shape of the tree and the characteristics of the root system can help locate the direction of prevailing winds. All conifers have their greatest radius on the leeward side of the tree (Fritzche, 1933). The direction of fall of living and dead trees closely indicates the direction of strong, local prevailing winds (Alexander and Buell, 1955).

The past history of an area is a good indicator of possible future events. Old windfalls present in an area indicate a lack of windfirmness (Alexander, 1972). Pits and mounds are excellent indicators of old windfalls (Ruth and Yoder, 1953).

Cutting lines near creeks are often unstable because they pass through wet soils which are conducive to shallow rooting and poor root anchorage (Gratkowski, 1956). It is important to identify extremely wet areas during the planning stage.

Plant communities are useful tools that can aid in identifying wet sites. Skunk cabbage (<u>Lysichiton camtschatcenis</u>) is a good indicator of very wet sites (Ruth and Yoder, 1953). Minore (1969) has studied the growth of skunk cabbage in the Oregon Coast Range. He found that skunk cabbage petiole lengths are related to water table depths. Many other plants are characteristically found in wet or dry sites. However, it is best to evaluate the moisture status of a site by working with a group of plants (Emmingham, 1977). Topography is also a good indicator of whether a site is wet or dry. Wet areas are often found in valley bottoms, draws, and more gentle terrain at higher elevations (Ruth and Yoder, 1953).

As shown by the above discussion, it is evident that the stream environment is dynamic and complex. Therefore a careful site by site analysis is a prerequisite to the design of an effective streamside buffer strip. There are no simple guidelines that be uniformly applied over a wide area. In conclusion, Froehlich (1975B) cautions that potential for windthrow and other losses should be carefully weighed before deciding to leave a buffer strip. In areas prone to windthrow, perhaps it may be better to carefully log the stream zone, at least taking those trees most susceptible to blowdown.

DESCRIPTION OF THE STUDY AREA

The study area is located on the western slope of the Oregon Cascades, from the North Umpqua River area east of Roseburg, to the Bull Run Watershed near Mt. Hood. All buffer strip samples are located on either U.S. Forest Service or Bureau of Land Management land.

Climate

The climate of the Western Cascades can be characterized as one having wet winters and relatively dry summers. In general, the climate can be classified as mild. Most often, winter precipitation comes from large frontal storms which originate in the Pacific Ocean. Annual precipitation varies from about 75 to 160 inches per year, with a large percentage falling as rain in the valley bottoms, and as snow above 4000 feet. About 75 percent of the precipitation comes between November and April, saturating the soil when storm winds are most common (Gratkowski, 1956). With increases in elevation, temperatures generally decrease and precipitation and snowfall increase. Temperatures vary from a winter low of -10°F, to summer highs of sometimes greater than 110°F (Franklin and Dyrness, 1973).

Winds throughout the Cascades are mainly from two sources: southwesterlies from the oceanic frontal storms, and easterlies from Foehns originating in the great basin to the east. Southwesterly winds are generally the most common. However, the less frequent east winds are often very intense, causing severe windthrow.

Unusual wind conditions exist in the Bull Run Watershed near Mt. Hood. Very high velocity east winds, frequently greater than 100 miles per hour, blow down the Columbia Gorge and over a major ridge paralleling the northern boundary of the watershed. The Bull Run Watershed is also exposed to the more common southwest winds.

Timber

Coniferous trees are dominant in the Western Cascades. The forest predominant in the study area is classed as the Tsuga heterophylla type. Trees in the Tsuga heterophylla zone are especially noted for their size, height, and longevity. Three main tree species are dominant: Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*). At higher elevations, noble fir (*Abies procera*), white fir (*Abies concolor*), grand fir (*Abies grandis*), and silver fir (*Abies magnifica*) are found growing in mixed stands with the more dominant trees.

Each tree species has a different longevity. Longevities for the most common tree species found in the study area are listed below:

1. Douglas-fir, 750 years plus,
2. western red cedar, 1000 years plus,
3. western hemlock, 400 years plus,
4. white fir, 300 years plus,
5. silver fir, 300 years plus,
6. noble fir, 400 years plus.

This study included stands which were decadent, as well as younger, vigorous stands (Franklin and Dyrness, 1973).

Terrain, Geology, and Soils

Terrain

Terrain in the study area is generally rugged and found between 2000 to 4000 feet in elevation.

Characteristically, the topography is deeply dissected, with fairly steep valleys. The small headwater streams used in this study contribute water to 7 major drainage systems: North Umpqua River, various forks of the Willamette River, McKenzie River, South Fork Santiam River, North Fork Santiam River, South Fork Clackamas River, and the Bull Run River.

Geology

The present geology of the Western Cascades is largely the result of many volcanic eruptions during the oligocene and miocene epochs. These eruptions have resulted in large deposits of basalts, andesites, and pyroclastic rocks. Glaciation, during the pleistocene epoch, has given major valley drainages their characteristic U-form.

Pyroclastic rocks make up 75 percent of the land area from the South Umpqua River to the McKenzie River. However, granitic material is often found in the North Umpqua River area. Andesite is very common between the North Fork of the Willamette River and the Clackamas River. Basalt occurs in scattered areas throughout the Western Cascades (Franklin and Dyrness, 1973).

Soils

The soils in the Western Cascades are derived chiefly from either basalts, andesites, and pyroclastics. Pyroclastic rocks weather easily to form fine textured soils. Soils formed from weathered pyroclastic rocks are often deep, poorly drained, subject to mass movement, and are silty or clayey textured. In contrast, soils derived from basalt or andesite weather more slowly, have coarser textures, better drainage, and are more stable than soils formed from pyroclastic parent materials.

Soils on steeper slopes are less developed than soils on flatter slopes,and usually have a gravelly loam texture. Deeper, loamier textured clays, loams, and clay loams are found on flatter sites. The soils at the northern end of the Oregon Western Cascades are more gravelly or stony. Many of the soils in the North Umpqua River area are derived from granite, and have a sandy texture.

METHODS

Observations and measurements of 40 streamside buffer strips were made to determine their survival and effectiveness. A variety of topographic settings, buffer strip widths, and stream orientations are represented in the samples.

Field Methods

Site Selection

Forest Service (USFS) and Bureau of Land Management (BLM) foresters helped mark potential buffer strips on 1 inch equals 1 mile fireman's maps. Both good and poor buffer strips were marked on the maps in an attempt to obtain a typical sample of conditions existing in the field. Then, each buffer strip was located in the field and judged for suitability as a possible sample. Several other buffer strips, located during field work, were also sampled.

Selecting buffer strips for this study was difficult. The main criteria used for selection was to choose those buffer strips that would give a reasonable sample of the conditions actually existing in the field.

Although care was taken to select a representative sample, a possible bias does exist. Older buffer strips that failed have probably been salvaged. Therefore, the oldest buffer strips in the sample are those that reflect a high degree of stability, and have withstood the test of time.

Forty buffer strips were finally chosen. They are located in the following forests:

1. North Umpqua District (BLM)-11 buffer strips,

2. Eugene District (BLM)-2 buffer strips,
3. Willamette National Forest (USFS)-20 buffer strips,
4. Mt. Hood National Forest (USFS)-7 buffer strips.

A map of Oregon, Figure 1, shows the location of these buffer strips.

Measurement Schedule

Most of the buffer strips in the North Umpqua Forest were measured in the summer of 1974. The following summer, several of the North Umpqua buffer strips were re-cruised, and initial measurements were made on almost all of the remaining buffer strips. Six new buffer strips were added during the summer of 1976, and all buffer strips were re-measured.

Initial Field Work

A 400-700 foot length of buffer strip was measured at each site. Each sample was then divided into 100 foot increments (stations), which were marked with flagging and aluminum tagging. Buffer strip width and hill slope were measured at each 100 foot station. Bearings between 100 foot stations, along the stream, were measured with a Silva hand cruiser's compass.

Timber Measurement

A gross timber volume estimate was made for each tree species by using a 100 percent cruise method. Total tree height and diameter measurements were made at each tree, with each tree being assigned to one of four groups: standing live, standing dying, standing dead,

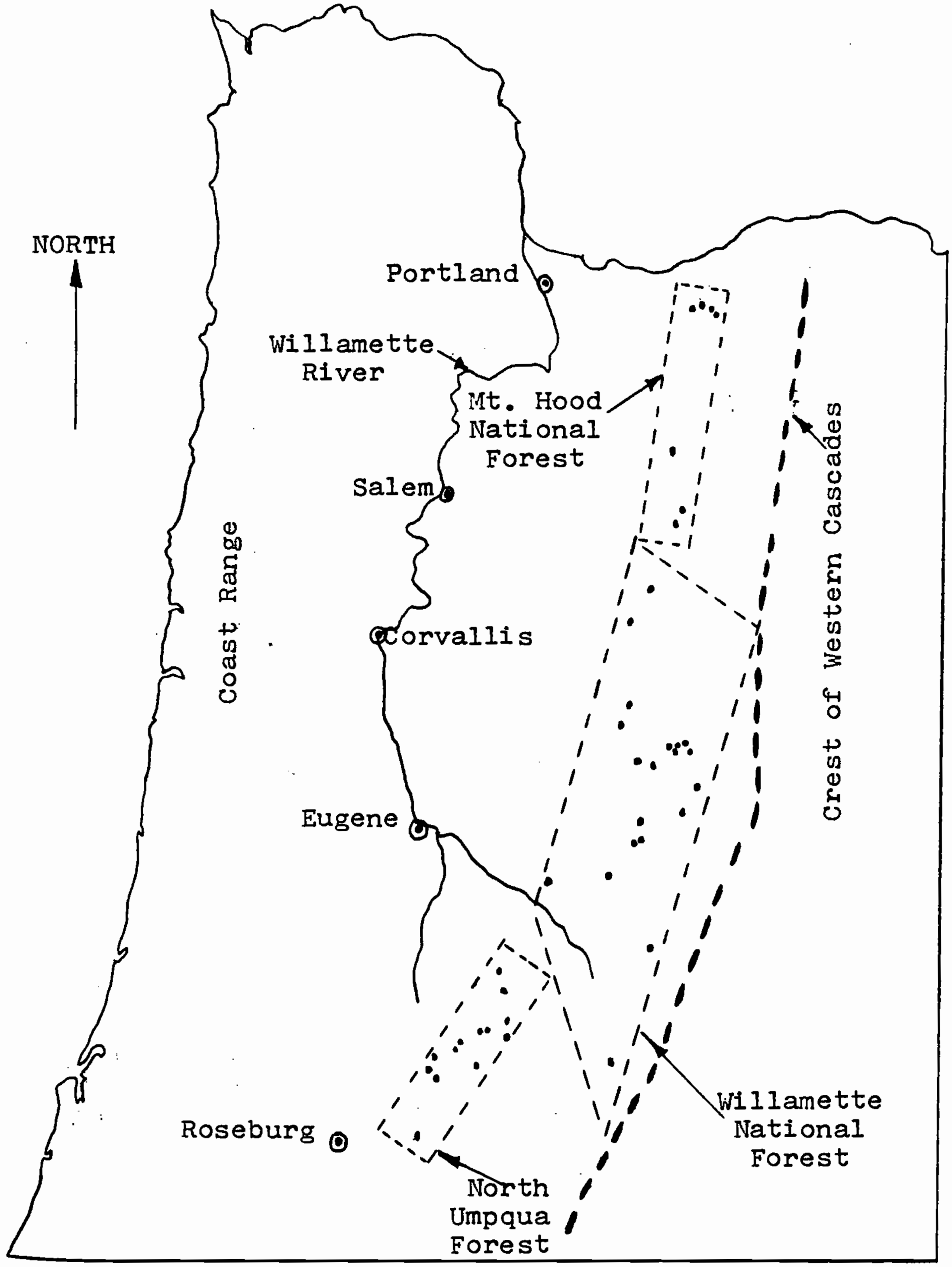


Figure 1. Buffer strip location map of Oregon.

and windthrown. Later, in the office, total tree heights and diameters were converted to gross volumes by using an appropriate volume table.

Each standing tree was checked for disease, insects, sunscald, and logging damage. Notes were made about unusual timber features at each site. For example, large amounts of stand defect, predominantly jackstrawed trees and old windfalls were noted as unusual features. The direction of fall was recorded for each windthrown tree. Wherever possible, rooting depth was estimated.

Understory Description

Understory plant communities may be a good indicator of the moisture status of a particular site. Major understory plants were identified at each site. A summary of the plants found at each buffer strip is tabled in Appendix 1. An estimate was made of average understory height and percent ground cover.

Soil Sampling

Soil samples were taken from small, narrow pits at chosen buffer strips. Soil depth was estimated wherever possible.

Topographic Setting

Notes were made about the general topographic setting for each buffer strip. Included in these notes were clearcut slope, aspect, and stability features. Special attention was paid to the location of saddles, sheltering ridges, swampy areas, and adjacent uncut timber stands.

Stream Notes

Besides the stream bearing measurements described earlier, several other observations about stream condition were made. They were:

1. evidence of undercutting,
2. evidence of minor slope failures,
3. presence of old windfalls,
4. location of large debris jams,
5. excessive amounts of logging debris.

Mapping

A plan sketch was made at each stream. The sketch included the following:

1. buffer strip width,
2. location of windthrow,
3. minor slope failures,
4. debris jams,
5. ridges or saddles,
6. location of virgin timber stands.

Photography

Color slides were taken of each buffer strip so that future changes can be easily seen. Unusual characteristics of each buffer strip were photographed. For example, some of the features photographed were: down timber, debris jams, and minor slope failures.

Buffer Strip Effectiveness

Buffer strip effectiveness is, essentially, how well a buffer strip is protecting the stream. An estimate of buffer strip effectiveness for stream shading can be made by measuring angular canopy density (ACD). Buffer strip effectiveness for debris blockage was not quantified.

ACD is a measure of how well the buffer strip is shading the stream. The angular canopy densiometer was developed by Brazier (1973), and subsequently modified by Froehlich (1974).

The modified angular canopy densiometer consists of a 1 foot square mirror, divided into 16 squares, which is set in a wooden frame mounted on a tripod with steel legs 26 inches long. To make a measurement of ACD, the densiometer is placed as close to the center of the stream as possible and oriented due south. Since heating by the sun's rays is most critical during low stream flows, about August 28, the mirror is tilted so it reflects the canopy shading at that time. The actual angle of tilt is equal to 1/2 the compliment of the maximum sun angle. Figure 2 shows a brief example of the mirror angle calculation.

The trees shading the stream can be seen when the mirror has been properly set up. Topography and understory brush shading the stream are visible too. The viewer estimates the percent of each small square blocked by the canopy, with the average of the individual estimates giving an overall value for ACD. A land manager can use the angular canopy densiometer to decide which trees are actually shading the stream. Therefore, trees not shading the stream can be removed.

ACD was measured at each 100 foot station. Several streams were deep and swift, so it was necessary to slightly offset the mirror from the stream center.

ACD measurements were made for 12 unlogged streamsides, whenever the adjacent buffer strip was not contributing to stream shading. For example, a buffer strip located on the north side of an east-west running stream does not shade the stream during the most critical time. Most shade would come from the virgin stand to the south. Therefore, ACD measurements for uncut stands were made when virgin timber was on the south side of a stream.

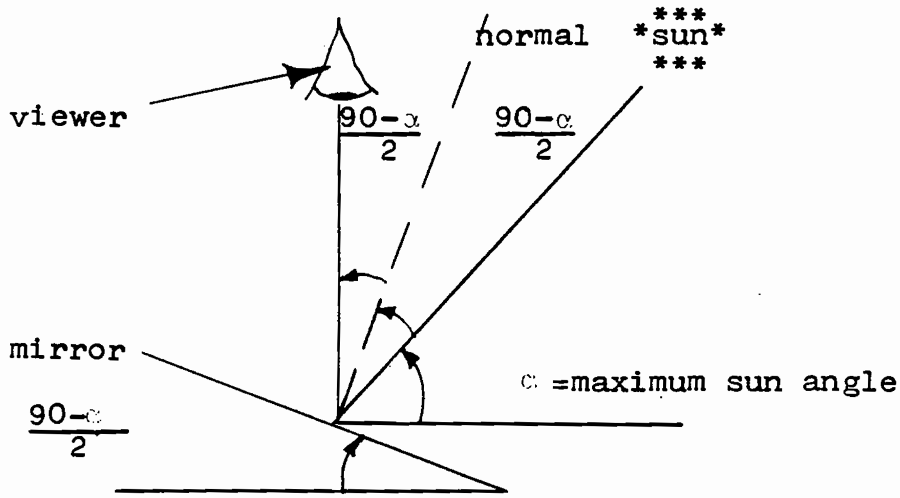


Figure 2. Calculation of mirror angle
(after Froehlich, 1974)

Piezometers

Several buffer strips were chosen for measurement of the winter water table. The literature provides evidence that saturated soils are unstable rooting zones for trees in windy areas, and may have a negative effect on the roots of Douglas-fir. It was possible to extensively investigate winter water table depth on 5 sites. Piezometers were installed in 4 unstable buffer strips and in 1 stable buffer strip. All piezometers were read in May and June, 1976. Afterwards, they were reset so additional measurements could be made in spring, 1977.

A piezometer records the highest level reached by the winter water table. Basically, a piezometer consists of two tubes and a few pieces of spaghetti styrofoam which float up in the inner tube. The small floats stick to the sides of the inner tube at the highest level of water rise. The piezometers used in this study were modeled after those constructed by Yee (1975). Figure 3 is a sketch of a typical piezometer installation.

The piezometer is made up of 6 main parts:

1. 3/4" pvc pipe (6 1/2 feet in length),
2. 3/8" clear acrylic tube (6 feet in length),
3. 3/4" rubber stopper,
4. spaghetti styrofoam (small pieces),
5. 1" plastic cap,
6. fine screen mesh.

Holes, 1/6 inch diameter, were drilled in the bottom 8 inches of the 6 1/2 foot length of pvc pipe. Small holes were then drilled in the bottom 4 inches of the acrylic tube. A rubber stopper was then cemented in the bottom of the tube. Next, a 10 inch wide strip of fine screen mesh was cemented to the bottom of the pvc pipe.

An Acker diamond bit rock drill was used to drill the piezometer holes. The holes, wherever possible, were drilled to a 6 foot depth. However, when a hard rock layer restricted drilling, holes were somewhat shallower.

After the hole was drilled, a few inches of fine white filter sand were poured in the bottom of the hole. Then, the piezometer was carefully lowered to the bottom of the hole, and more fine gravel was poured to cover the small holes in the side of the piezometer. Next, about 7 inches of bentonite clay were poured down the sides of the hole. Finally, the rest of the hole was backfilled with leftover soil.

Three small pieces of spaghetti styrofoam were placed in the bottom of the clear acrylic tube. Then, the clear acrylic tube was lowered down to the bottom of

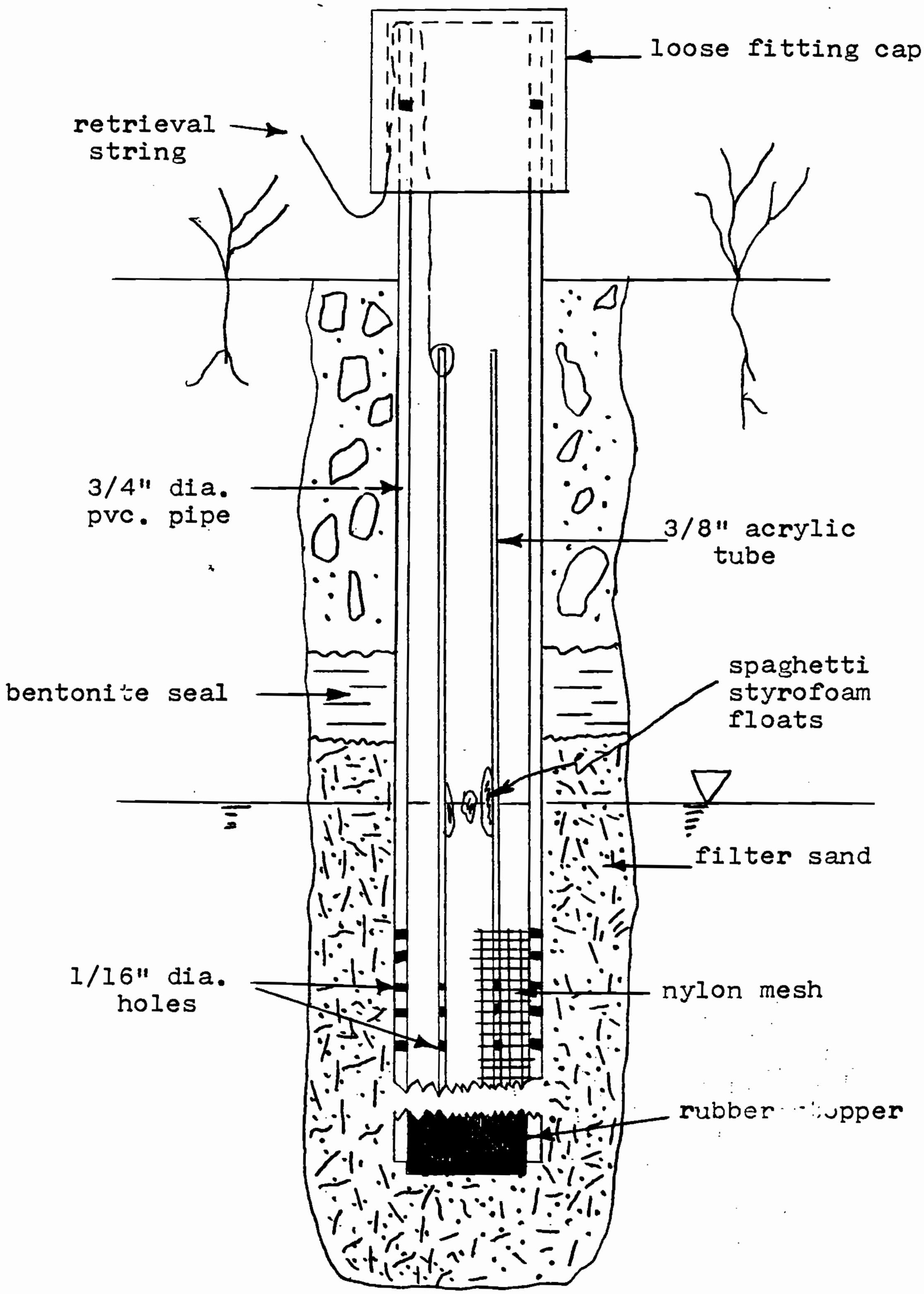
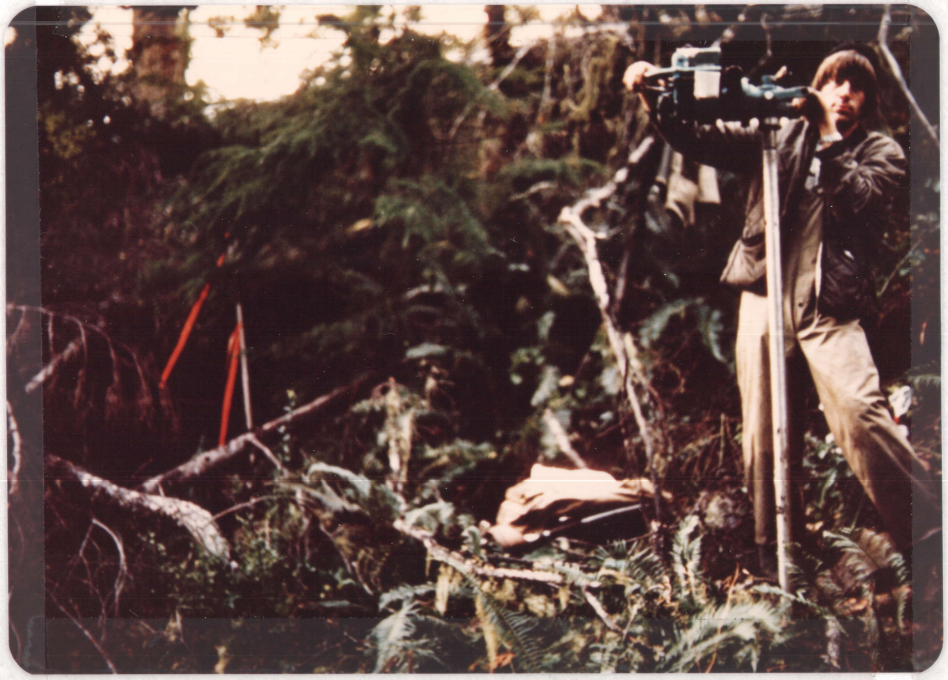


Figure 3. A typical piezometer installation. (after Yee, 1975)



a. Acker diamond bit rock drill at Winberry Creek buffer strip

b. A typical piezometer installation at the Deer Creek buffer strip

Figure 4. Examples of piezometers

of the hole, and more fine gravel was poured to cover the small holes in the side of the piezometer. Next, about 7 inches of bentonite clay were poured down the sides of the hole. Finally, the rest of the hole was backfilled with leftover soil.

Three small pieces of spaghetti styrofoam were placed in the bottom of the clear acrylic tube. Then, the clear acrylic tube was lowered down to the bottom of the 3/4 inch pvc pipe. The final step was to put a loose fitting cap on top of the pvc pipe. Figure 4 is a series of photographs showing a piezometer and the Acker diamond bit rock drill.

Office Methods

This section describes the methods used to analyze data collected during field work.

Variable Definitions

Definitions of variables that are frequently used in this section, and throughout the rest of this study are given in Table 1.

Table 1. Variable Definitions and Abbreviations

ACD: the percent of canopy that will be shading the stream at the most critical time.

AVHTALL: average height (feet) of all initial buffer strip trees.

AVHTTALL: average height (feet) of all initial buffer strip trees taller than 100 feet.

DIRWIND: the direction from which damaging prevailing winds originate (1 to 8 in 45^{o} segments).

DISTWIND: the distance (feet) from the upper edge of the buffer strip to the cutting line in the direction of damaging winds.

ELEV: elevation above mean sea level of the mid-point of the buffer strip (feet).

ELEVRIDG: the change in elevation from the mid-point of the buffer strip to the top of the nearest major ridge in the direction of damaging winds (feet).

DISTRIDG: the distance (feet) to the nearest major ridge in the direction of damaging winds.

EXPCODE: a code describing the amount of exposure of a buffer strip to damaging prevailing winds.

LOGDAM: the number of trees per acre of buffer strip damaged by logging.

NOSTEMS: initial number of trees per acre in the buffer strip.

NETGROSS: the estimated percentage of total volume of buffer strip trees which is sound wood.

NOSIDES: the number of sides a buffer strip is exposed.

NOTALL: the initial number of buffer strip trees taller that 160 feet, expressed on a per acre basis.

NOSMALL: the initial number of trees shorter than 100 feet, expressed on a per acre basis.

NOWINTERS: the number of winters a buffer strip has been exposed (as of September, 1976).

ORIENT: direction of stream flow. NW or SW streamflow equals 1, while NE or SE streamflow equals 2.

OVSPECIE: a code describing the initial composition of buffer strip overstory species.

ORIGVOL: original, after timber harvesting, gross timber volume per acre (MBF).

ORIGBA: original, after timber harvesting, gross timber basal area per acre (square feet).

SLPCRK: average percent side slope into creek (i.e.: 70%).

SLPCC: average percent clearcut slope (i.e.: 70%).

SOILDPT: average soil depth (feet).

STABRATE: a code giving the estimated natural stability of the buffer strip vicinity.

SLPWIND: percent slope to the cutting line in the direction of damaging prevailing winds (i.e.: 30%).

TOWNSHIP: a numerical value expressing the distance north or south of the Willamette base line, in increments of 6 miles.

UNSPECIE: a code for understory plant species moisture class, ranging from 1 for dry sites, to 4 for very wet sites.

VERTHOR: a slope factor equal to 100* (ELEVRIDG/DISTRIDG), which describes the percent slope to the nearest major ridge in the direction of damaging winds.

VOLTREE: average, initial buffer strip volume per tree (MBF).

VOLREM: the percent of initial buffer strip volume remaining, reflecting all losses.

WETVOL: an interaction term (UNSPECIE * ORIGVOL).

WIDTH: width of the buffer strip (feet).

Volume and Basal Area Calculation

Gross timber volume (bd. ft.) was calculated for each tree by using total tree height volume tables (Johnson, 1955). Individual tree volumes were assigned to one of four categories: standing live, standing dead, standing dying, and windthrown, depending on the physical condition of the tree. Gross timber volume was divided by buffer strip area to get a volume estimate on a per acre basis. Similarly, gross basal area and gross basal area per acre were calculated for each tree species.

Timber volumes were computed for sampled length, and total length of each buffer strip. Total volume was estimated by multiplying the sampled section volume by estimated buffer length.

Windthrow Analysis

An important objective of this study was to quantify the amount of windthrow in stream buffer strips. As discussed in the literature review, most researchers assume the direction of fall is also the direction of prevailing winds. Therefore, the direction of fall was recorded for each windthrown tree to get an estimate of the direction of damaging prevailing winds (DIRWIND). Windthrown trees in each buffer strip were assigned to 1 of 8 classes, depending on the direction of fall. The 8 classes are listed below:

1. Due N to N 45° E
2. N 45° E to due E
3. Due E to S 45° E
4. S 45° E to due S
5. Due S to S 45° W
6. S 45° W to due W
7. Due W to N 45° E
8. N 45° E to due N

After windthrow had been tallied in each buffer strip, a summary windrose was constructed for each individual forest, and for all forests combined. The windroses are shown and described in the results.

Understory Species Evaluation

Major understory plants were identified at each buffer strip. The tabulated arrays of species are given in Appendix 1. Bill Emmingham, forest ecologist at the Oregon State University Forest Research Lab, devised a method for grouping the plants at each site into different moisture classes (UNSPECIE). Four classes were used: 1 being a very dry site, 2 a modal site, 3 a wet site, and 4 a very wet site.

Key groups of indicator plants were used to assign a buffer strip to a particular moisture class, as shown in Table 2. If 1 or 2 plants from group 4 were fairly widespread in a buffer strip, moisture class 4 (very wet) was assigned. Similarly, buffer strips were assigned to moisture class 3 (wet). Group 2 (modal) consists of plants that are common to a site of average moisture. Group 1 (dry) consists mainly of dry site species.

Table 2. Plant Moisture Groups

Moisture group	Plants
	skunk cabbage (*Lysichitum americanum*)
4 - very wet	sedges (*Carex spp.*)
	devils club (*Oplopanax horridum*)
	salmonberry (*Rubus spectabilis*)
	red alder, widespread (*Alnus rubra*)
	coltsfoot (*Maianthemum dilatum*)
3 - wet	lady fern (*Athyrium filix-femina var. californicum*)
	oxalis (*Oxalis oregana*)
	red huckleberry (*Vaccinium parvifolium*)
	vanilla leaf (*Achlys triphylla*)
	dogwood (*Cornus spp.*)
	swordfern (*Polystichum munitum*)
2 - modal	rhododendron (*Rhododendron spp.*)
	bracken fern (*Pteridum aquilinum*)
	vine maple (*Acer circinatum*)
	salal (*Gaultheria shalon*)
	hazel (*Corylus spp.*)
1 - very dry	Oregon grape (*Berberis nervosa*)
	ocean spray (*Holodiscus discolor*)

Assigning the buffer strips to moisture classes was often difficult, and involved exercising considerable judgement. Field notes made during the timber cruise were used to help assign moisture classes in borderline cases.

Angular Canopy Density

ACD readings were taken at 100 foot intervals along the buffer strip. Individual readings were averaged to arrive at an ACD for the whole buffer strip. These values were placed in two groups: shading from buffer strip, and shading from the virgin timber. The ACD values for uncut stands were tabulated to get an idea of the range of angular canopy densities found naturally.

An analysis was performed to determine the simple correlation between ACD and several buffer strip characteristics: width, timber volume, tree height, stand density and slope into creek. Next a multiple regression analysis was run with ACD and the independent variables found significant in the correlation.

Topographic Setting Analysis

A field and topographic map study was made of the topography surrounding each buffer strip-clearcut unit. This included a study of the location of clearcut boundaries with respect to each buffer strip.

Each clearcut unit was mapped on a 7 1/2 minute or 15 minute U.S.G.S. topographic map. Fireman's maps and individual timber sale maps were used as a reference for drawing the unit boundaries on the U.S.G.S. topographic maps. Many basic measurements were made off the U.S.G.S. topographic maps. They were:

1. length and width of clearcut
2. clearcut slope (SLPCC).
3. elevation at midpoint of buffer strip (ELEV).

Clearcut slope (SLPCC) and slope into creek (SLPCRK) were measured during field work. These measurements were checked against those taken off the topographic map.

Winds over the study area generally come from the southwest or the east. Buffer strips exposed to winds from either of these directions often had severe windthrow. The tally of windthrown trees in each buffer strip was used as an indicator of the direction of damaging prevailing winds (DIRWIND).

A careful analysis of each clearcut unit was made to determine whether or not a buffer strip was exposed to either southwest or east winds. Appendix 2 shows a small map of each buffer strip clearcut unit. This analysis involved studying the proximity of the buffer strip to nearby uncut stands. Field notes and the clearcut outlines on topographic maps were used to determine if the buffer strip was exposed to potentially damaging winds.

Figures 5 and 6 show a hypothetical buffer strip which will be used to illustrate several measurements. For example, in Figure 5 the buffer strip is exposed to both the southwest and east. The windthrow tally shows that most of the trees have fallen towards the west, indicating that the winds from the east have been the most damaging. Perhaps some feature of the clearcut and topography to the southwest has protected the buffer strip from southwest winds, but for all practical purposes, the buffer strip is actually exposed to the southwest and east.

Different codes (EXPCODE) were assigned to each buffer strip, depending in which direction the buffer strip was exposed. The codes are listed below:

1. not exposed,
2. exposed to southwest,
3. exposed to east,
4. exposed to southwest and east.

Another factor influencing wind passage through the clearcut is the distance from the buffer strip to the cutting line in the windward direction (DISTWIND). Since most of the windthrown trees in the buffer strip, shown

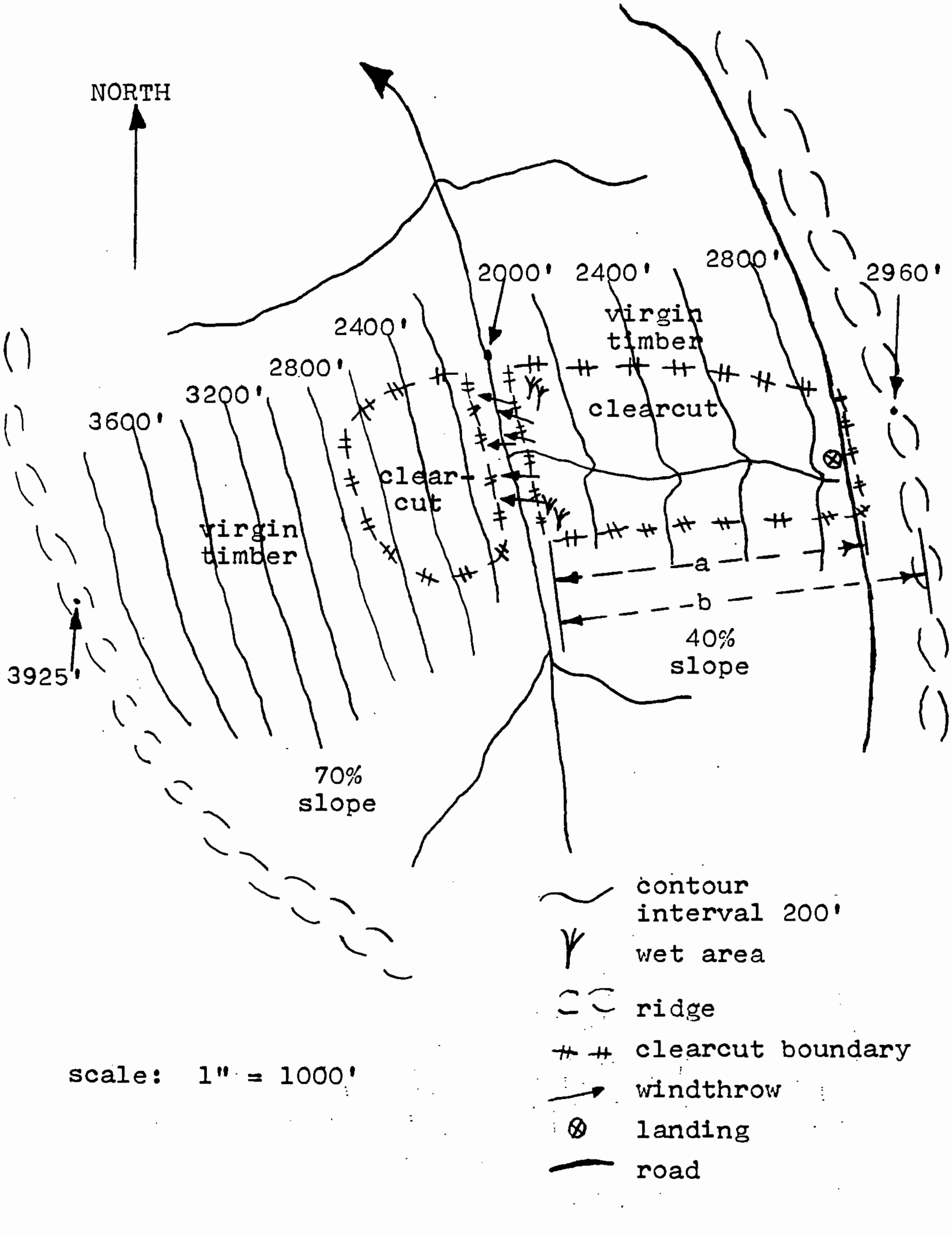


Figure 5. Plan view of measurement example.

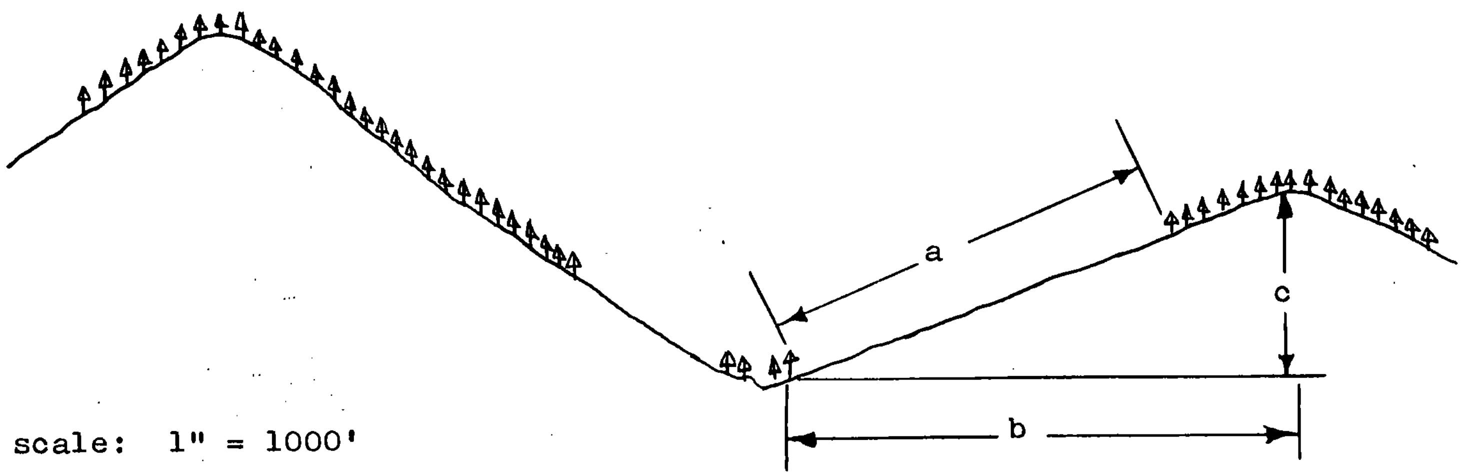


Figure 6. Profile view of measurement example.

in Figure 5, have fallen to the west, it is assumed the most destructive winds came from the east. The slope distance along the dashed line (a), 2085 feet, is the distance to the cutting line in the windward direction.

The slope in the windward direction (SLPWIND) may be another factor determining how much protection is given by the topography. The slope in the windward direction is about 40 percent for the hypothetical buffer strip.

If steep enough, a major ridge in the windward direction will shelter the buffer strip. Three factors were used to describe the degree of shelter provided by a major ridge: 1) horizontal distance from the buffer strip to the ridge (DISTRIDG), 2) change in elevation from the buffer strip to the ridge (ELEVRIDG), and 3) a slope factor (VERTHOR), which equals (ELEVRIDG/DISTRIDG) * 100. For the buffer strip shown in Figures 5 and 6, DISTRIDG is the length of the dashed line (b), about 2280 feet. ELEVRIDG is shown in Figure 6 as a line (c), which is 900 feet. The slope factor (VERTHOR), is (900/2280) * 100 or 39 percent. In this buffer strip, because of the uniform slope, VERTHOR is equal to the slope in the windward direction (SLPWIND).

Stream orientation (ORIENT) was another factor used to describe the amount of topographic protection near a buffer strip. Streams flowing to the northwest or southwest have a westerly aspect, and were assigned an ORIENT value of 1, while streams flowing to the northeast or southeast have an easterly aspect, and were assigned an ORIENT value of 2. The hypothetical stream in Figure 5 is flowing to the northwest, and is assigned an ORIENT value of 1.

Natural Stability

The natural stability of the buffer strip area is a site factor, and may help explain whether or not a buffer strip will be windthrown. In this study, natural stability is the degree of stability in an area prior to disturbance by man.

Natural stability of each buffer strip site was estimated from three sources: field notes, aerial photographs, and soil surveys. Slumps, slides, bank failures and other indicators of instability were noted during field work. Field observations were combined with a study of aerial photographs at USFS and BLM district offices. Each district soil scientist gave considerable assistance with interpreting the natural stability of different sites. Local soil surveys were also used as an aid for judging stability. However, most emphasis was placed on field notes and interpretation of aerial photographs.

Each buffer strip was placed in one of three stability classes (STABRATE), depending on the natural stability of the area. The following three classes were used:

1. naturally stable,
2. naturally moderately stable,
3. naturally unstable.

Basic Soils Data

Soil depth may be an important factor which influences the stability of trees at a site. General soils information was obtained three ways: USFS or BLM soil survey reports, field notes when soil depth was estimated, and hydrometer and sieve particle size analysis. USFS and BLM soil surveys indicated soil texture and depth. Soil depth (SOILDPT) estimates were obtained mostly from soil surveys. Field estimates of soil depth were made only when the soil profile was exposed. Lab textural analysis was used to obtain soil texture.

Buffer Strip Mapping and Area Determination

Each stream channel was plotted, in plan, by using a Hewlett-Packard (HP) model 9830 computer with a plotter. Stream bearings, from one station to the next, were fed into the HP, which uses an open-traverse program to plot the plan view of a stream channel. Buffer strip width was plotted, by hand, on the plan map. Buffer strip width (WIDTH) was calculated from slope distance and slopes measured during the cruise. Area for each buffer strip was measured with the HP-9830 digitizer.

The following other features were plotted for selected buffer strips: topography, unusually large debris jams, swampy areas, dead standing trees, and trees damaged during logging. Piezometers were located on the plan maps for the five buffer strips in which they were installed.

Additional Timber Factors Used for Regression Analysis

A number of other timber factors were needed for the multiple regression analysis to be described later. They were:

1. AVHTALL	3. LOGDAM	5. NOSTEMS
2. AVHTTALL	4. NOSMALL	6. NOTALL

7. ORIGBA 9. OVSPECIE 11. VOLTREE
8. ORIGVOL 10. VOLREM 12. WETVOL

VOLREM is a variable that describes the percentage of initial timber volume remaining in a buffer strip, only considering losses from windthrow. All other losses (insects, sunscald, fire) are included in the total volume remaining estimate (VOLREM*).

Two variables were used to describe buffer strip tree height. AVHTALL is the arithmetic average of the heights of all buffer strip trees. AVHTTALL is the arithmetic average of all tree heights greater than 100 feet.

Three variables were used to describe stand density. NOTALL expresses the number of trees taller than 160 feet, on a per acre basis. Similarly, NOSMALL expresses the number of trees less than 100 feet tall, on a per acre basis.

WETVOL is an interaction term which was devised to test the hypothesis that large timber volumes or large trees, on wet sites, are more susceptible to windthrow. WETVOL was computed by multiplying UNSPECIE * ORIGVOL.

LOGDAM was used to quantify the amount of logging damage at each buffer strip. Amount and kind of logging damage was tallied for each buffer strip. To arrive at LOGDAM, all trees damaged by logging were tallied together and then divided by buffer strip area.

OVSPECIE describes the original, after logging, stand composition in the buffer strip. A number from 1 to 8 was assigned to each buffer strip, depending on which species of trees were present. Numerical values for OVSPECIE are listed below:

1. 100% hardwoods,
2. Douglas-fir greater than or equal to (GT. or EQ.) 75% of volume,

3. Douglas-fir GT. or EQ. to 75% of volume plus true fir.
4. Douglas-fir GT. or EQ. to 50% of volume.
5. Douglas-fir GT. or EQ. to 50% of volume plus true fir.
6. Hemlock and cedar GT. or EQ. to 50% of volume.
7. Hemlock and cedar GT. or EQ. to 75% of volume.
8. Hemlock and cedar GT. or EQ. to 75% plus true fir.

For OVSPECIE codes in which Douglas-fir is listed by itself, it is assumed that the remaining volume is made up of hemlock and cedar. Likewise, when hemlock and cedar are listed by themselves, it is assumed that Douglas-fir makes up most of the remaining volume. True fir occupies more than 5 percent of the total volume in only 4 buffer strips: Davey Creek (33%), South Fork of the Clackamas River (15%), Whetstone Creek (18%), and Bedrock Creek (7%).

Three other variables describing buffer strip timber after logging are: ORIGVOL, ORIGBA, and VOLTREE. The original gross buffer strip volume per acre (ORIGVOL) was calculated by summing timber volumes in the following categories: living, standing dead, standing dying, and windthrown. In a similar way, the original gross basal area per acre (ORIGBA) was calculated, except that individual tree basal areas were summed. The original gross volume per tree (VOLTREE) was calculated by summing up original gross tree volumes, and then dividing by the total number of trees.

Timber Value Calculation

An average timber value was calculated for each buffer strip. Average stumpage values were obtained from the USFS and BLM. An average stumpage value was chosen for use in all buffer strips. No attempt was made to make an appraisal of each individual buffer strip. The sole purpose of these calculations is to give an approximation of the timber value in each buffer strip.

Since the same stumpage value was used throughout the calculations, it is assumed that the market value of the timber remains unchanged. The following stumpages were applied uniformly to each buffer strip:

Douglas-fir	$210/MBF/net
Western hemlock	$135/MBF/net
Cedar	$130/MBF/net
True fir	$135/MBF/net

Average stumpage value was multiplied by the net volume for each species to arrive at net buffer strip timber value. First, an original net value was calculated for each buffer strip. Then, after each re-observation, a new value was calculated. Each new value was subtracted from the previous year's value to get a value for the timber lost over the winter. The results of the calculations are shown in the results, and tabulated in Appendix 3.

Timber Quality Estimate

An estimate of timber defect was obtained from USFS and BLM records. Usually it was possible to obtain a quality estimate by species. However, in a few cases the defect estimate was combined for all species. These estimates obtained from government records were supplemented by occasional notes made during the cruise. The percentages of buffer strip volume in sound wood are tabulated in Appendix 4.

USFS Tri-Card and Miscellaneous Record Search

Throughout the study, USFS and BLM records were searched for the following information:

1. year of logging for clearcut unit above the buffer strip;
2. past salvage history of the buffer strip;
3. timber quality estimate;
4. environmental impact reports.

Statistical Analysis

Multiple Linear Regression

A multiple linear regression analysis was run on 1 dependent variable, VOLREM, and 29 independent variables. Thirty-nine samples were used in this regression: 26 in Willamette and Mt. Hood National Forest, and 13 in the North Umpqua and Eugene districts of the BLM. All variables used in the regression are listed below:

1. VOLREM (dependent)	11. SLPCC	21. AVHTTALL
2. ELEV	12. SLPCRK	22. NOTALL
3. ELEVRIDG	13. SLPWIND	23. NOSMALL
4. TOWNSHIP	14. EXPCODE	24. ORIGVOL
5. DISTRIDG	15. VERTHOR	25. ORIGBA
6. LOGDAM	16. ORIENT	26. NOSTEMS
7. DISTWIND	17. STABRATE	27. WETVOL
8. ACD	18. SOILDPT	28. VOLTREE
9. UNSPECIE	19. WIDTH	29. NETGROSS
10. OVSPECIE	20. AVHTALL	30. NOSIDES

The first step in this analysis was to create a data file on OS-3, one of the computer systems at Oregon State University. All variables were listed in a large table and then punched on computer cards. A short program was used to store the data in the computer. The data was analyzed with the Statistical Interactive Programming System (SIPS), an interactive statistical package on OS3.

A simple correlation was obtained between all variables used in the regression by using SIPS. Several simple regressions, multiple regressions, and variable descriptions were made using SIPS. The multiple regression equations are described in the results and discussion section. Appendix 4 contains a complete set of the basic data used in the multiple regression.

Chi-square Contingency Tables

Chi-square contingency tables were used to determine if:

1. trees taller than average blow down at a greater rate than trees shorter than average;
2. trees with diameters greater than average are blowndown at a greater rate than trees below average diameter;
3. trees of different species blow down at significantly different rates.

The first step in this analysis was to tally the trees in each buffer strip according to their condition. Then, the tallies for all the buffer strips were summed into two groups. One group was formed by summing up all individual buffer strip tallies. The second group was formed by summing up the tallies for the buffer strips which had at least 13 percent of the original buffer strip volume windthrown (susceptible buffer strips). When these tallies were completed, chi-square contingency tables were constructed in order to test the hypothesis listed above. The hypothesis were tested separately for the pooled buffer strip tally and the susceptible buffer strip tally.

Laboratory Methods

Soil Textural Analysis

Two laboratory tests were used to determine soil texture:

1. Buoyoucos hydrometer analysis;
2. Sieve particle size analysis.

The Buoyoucos hydrometer test was run using standard procedures, and gave an estimate of percent sand, percent silt, and percent clay. Larger particle sizes were evaluated with a standard sieve analysis. The following sieve sizes were used: 1 inch, 1/2 inch, 1/4 inch, #4, #10, #40, and #100. On the basis of these tests, a textural class was assigned to the soil samples. Soil tests were run on soil samples taken from selected buffer strips.

RESULTS AND DISCUSSION

The results of the observations on survival, effectiveness, and design of buffer strips, interwoven with a discussion, will be presented in three parts: buffer strip survival, buffer strip effectiveness, and buffer strip design for survival.

Buffer Strip Survival

Buffer strip survival was quantified by direct measurement of approximately 4.0 million (MM) board feet of timber left for streamside buffer strips. The estimated total timber volume left in the buffer strips sampled in this study amounts to about 8.4 MM board feet.

Volume remaining (VOLREM*) in the 40 buffer strips sampled ranged from 22 to 100 percent of the original volume. The mean timber volume remaining in the buffer strip samples was 81 percent, while the median volume remaining was 91 percent.

Wind caused the greatest percentage of buffer strip mortality. The photographs in Figure 7 show the Owl Creek buffer strip, which suffered severe windthrow during the winters of 1974 and 1975.

In addition to windthrow, other losses occur which leave the tree standing. Table 3 summarizes all losses. Detail on each buffer strip's volumes and losses is tabulated in Appendices 5 and 6. The information is summarized by year, so the effect of one additional winter on buffer strip losses can be evaluated. Table 4 contains the volume changes which occurred over the winter of 1975-1976 in each of the following categories: living, down, dead, and dying. The information is summarized by national forest area.

a. Owl Creek buffer strip, August, 1975

b. Owl Creek buffer strip, August, 1976

Figure 7. Over the winter windthrow losses at the Owl Creek buffer strip

Table 3. Summary of Buffer Strip Losses

	standing			
	living	dead	dying	blowdown
initial sample 1975 number 34	85.3%	2.5%	2.1%	10.1%
initial sample 1976 number 34	80.3%	2.5%	2.1%	15.1%
one year change	- 5.0%	0.0%	0.0%	5.0%
pooled sample 1975 number 40	86.4%	2.6%	1.7%	9.3%
pooled sample 1976 number 40	73.0%	2.6%	1.7%	22.7%
one year change	-13.4%	0.0%	0.0%	14.4%

The initial sample includes the buffer strips cruised during the 1974 and 1975 field seasons. In the summer of 1976 several additional buffer strips were cruised. All buffer strips were re-measured during the 1976 field season. This third season's sample was found to be more susceptible to blowdown. These additional buffer strips may bias the sample towards more losses, but were included to give important clues about the factors leading to greater windthrow problems.

In 1975, there was 85.3 percent of the original timber left standing in the initially sampled buffer strips, while 86.8 percent of the original timber was left standing in all buffer strips combined (pooled sample). Dead and dying trees, combined, total 4.6 percent and 5.2 percent respectively of the initial sample and pooled sample buffer strip volume. Thus, mortality due to windthrow was about 10 percent of original and pooled buffer strip volume by 1975.

Additional windthrow losses occurred over the winter of 1975-1976. Along with the usual southwesterly winds,

Table 4. Buffer Strip ~~Value~~ Volume and Loss Summary
(by forest, thousands of board feet)

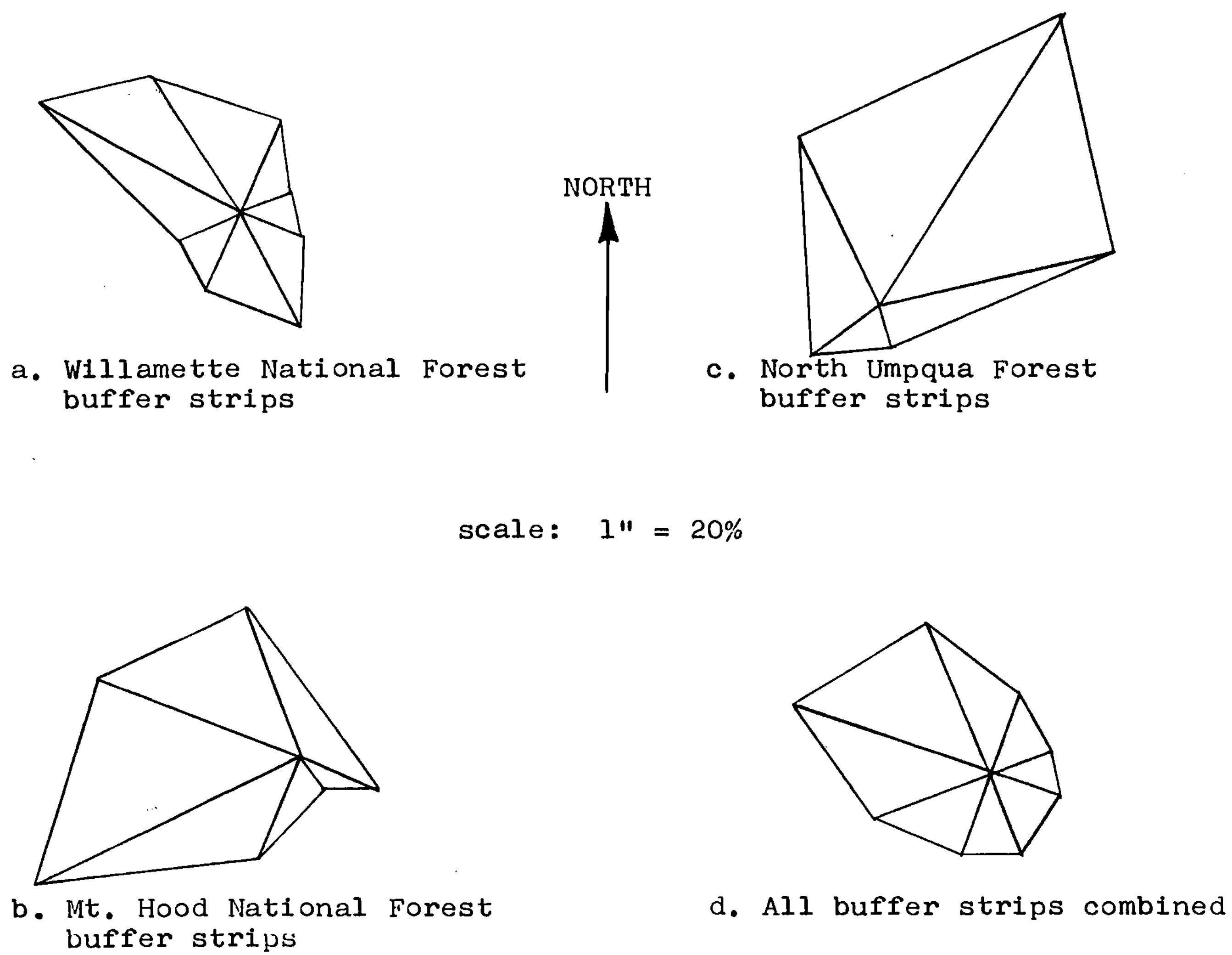
Forest Area	1975 living	1976 living	chng.	1975 down	1976 down	chng.	1975 dead	1976 dead	chng.	1975 dying	1976 dying	chng.
Mount Hood Forest												
init. buffers total vol.	955.0	927.8	27.2	169.0	195.0	26.0	106.4	107.6	1.2	18.0	18.0	0.0
pooled buffers tot. vol.	1953.0	1153.8	799.2	169.0	967.0	798.0	106.4	107.6	1.2	18.0	18.0	0.0
initial samples tot. vol.	502.0	479.5	22.5	112.0	134.0	22.0	49.0	49.5	0.5	8.0	8.0	0.0
pooled samples tot. vol.	710.0	526.5	183.5	112.0	295.0	183.0	49.0	49.5	0.5	8.0	8.0	0.0
Willamette Forest												
init. buffers tot. vol.	3777.0	3545.0	232.0	347.9	579.9	232.0	56.4	56.4	0.0	87.5	87.5	0.0
pooled buffers tot. vol.	4368.0	4004.0	364.0	423.9	1037.9	654.0	79.8	79.8	0.0	89.3	89.3	0.0
init. samples tot. vol.	1987.0	1876.6	110.4	210.3	320.7	110.4	21.4	21.4	0.0	47.8	47.8	0.0
pooled samples tot. vol.	2383.0	2081.6	301.4	252.3	553.7	301.4	34.4	34.4	0.0	48.8	48.8	0.0
North Umpqua Forest												
init. buffers tot. vol.	594.9	543.0	51.9	18.7	70.6	51.9	20.9	20.9	0.0	29.5	29.5	0.0
pooled buffers tot. vol.	796.2	685.3	110.9	23.7	134.6	110.9	31.9	31.9	0.0	31.5	31.5	0.0
init. sample tot. vol.	295.8	266.3	29.5	8.3	37.8	29.5	11.8	11.8	0.0	11.6	11.6	0.0
pooled sample tot. vol.	417.8	357.3	60.5	12.3	72.8	60.5	20.8	20.8	0.0	13.6	13.6	0.0
Grand Totals												
init. buffers tot. vol.	5326.9	5015.8	311.0	536.0	846.0	310.0	183.7	184.9	1.2	135.0	135.0	0.0
pooled buffers tot. vol.	7417.0	5843.0	1574.0	617.0	2190.0	1573.0	218.0	219.2	1.2	139.0	139.0	0.0
init. samples tot. vol.	2785.0	2622.0	163.0	330.0	493.0	163.0	82.0	82.5	0.5	67.0	67.0	0.0
pooled samples tot. vol.	3511.0	2965.0	546.0	377.0	922.0	545.0	104.0	104.5	0.5	70.0	70.0	0.0

a very strong storm system came from the east on February 17, 1976. This storm system brought with it severe winds, causing widespread windthrow over most of the Western Cascades. After the winter of 1975-1976, the percentage of windthrown timber had increased to 15.1 percent in the initial sample, and to 22.7 percent in the pooled buffer strip sample; a loss of 5 to 13 percent additional volume in one relatively mild winter. Much of the damage was localized. Windthrow in several individual buffer strips was catastrophic, while in other buffer strips only one or two trees were windthrown.

East winds caused the most damage on the Mt. Hood and Willamette National Forests, with southwesterly winds causing the most damage in the North Umpqua area buffer strips. In contrast, buffer strips in the North Umpqua area suffered almost no mortality due to east winds. Wind damage did occur from southwest and northwest winds in the Willamette National Forest.

Windroses showing the percentage of buffer strip trees falling in each direction are shown in Figure 8. The windroses were constructed from the number of windthrown trees located in the sample portion of the buffer strip. A major simplifying assumption underlying the results shown in the windroses is that the direction of fall for each windthrown tree represents the true direction from which the damaging winds originated.

Tree mortality in the dead or dying tree category remained largely unchanged after the winter of 1975-1976. Therefore, it is apparent that there is a sharp difference between the rate of tree mortality due to windthrow, and that due to disease or insects. Windthrow damage is often sudden, taking many trees at one time. Mortality from disease or insects occurs at a much slower rate, which is



a. Willamette National Forest buffer strips

b. Mt. Hood National Forest buffer strips

c. North Umpqua Forest buffer strips

d. All buffer strips combined

Figure 8. Windroses showing windthrow percentages in each direction.

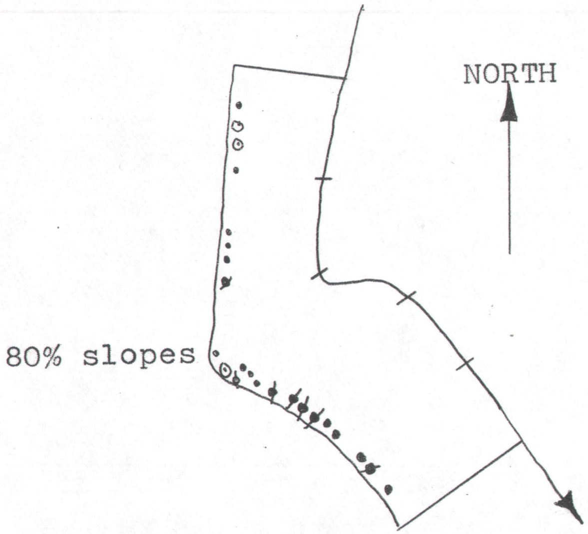
extremely difficult to detect over the period of one year.

Although logging damage has resulted in little noticeable damage to buffer strips, it is likely that its impact will be more evident with time. Figure 9a is a sketch of a buffer strip below an 80 percent slope. Several of the trees near the top edge of the buffer strip were used as anchors, or damaged by moving cables. Other trees were mechanically damaged by falling trees or rolling logs. Damage of this type is common on steeper slopes. The simple correlation between the number of trees damaged by logging per acre (LOGDAM) and clearcut slope is 0.554, significant at $\alpha = 0.01$. This implies that on steeper slopes there are more trees damaged by logging at the top edge of the buffer strip.

Figure 9b shows a western hemlock which had basal wounds due to logging. Later the same tree was further damaged by a falling tree. It is possible that these wounds will hasten the entry by insects or disease. Root rots may enter wounds close to the root collar. Gradually over a period of years the tree may become weakened to the point that it can no longer hold its own weight. Then, when it falls, it may mechanically damage another nearby tree. Therefore, over the long run, this type of damage may gradually chip away at the buffer strip, eventually leading to significant losses.

Table 5 gives a percentage survival comparison between forests. Measurements indicated that 74.8 percent of the original volume was still standing in the Mt. Hood National Forest buffer strips, 87.7 percent standing in the Willamette National Forest buffer strips, and 90.3 percent standing in the North Umpqua area buffer strips.

Table 5 shows that buffer strips located further south had better survival. Why is this so? Several simple correlations run between variables used in the



- dead tree
- damaged by logging
- dying tree

scale: 1" = 200'

a. Cook Creek buffer strip

b. Western hemlock damaged by logging and windfall at Wolf Creek 3 buffer strip

Figure 9. Examples of logging and windfall damage.

multiple regression may help explain why there was better survival in the buffer strips located further south. They are listed in Table 6.

VOLREM was significantly negatively correlated with ORIGVOL, ELEV, VOLTREE, and DISTRIDG. Taken as a whole, this information means that buffer strips had poorer survival if they possessed the following characteristics: large timber volumes per acre, large volumes per tree, situated at higher elevations, and located further away from sheltering major ridges.

The correlations also mean that buffer strips located further south tended to have lower volumes per acre, smaller volumes per tree, drier sites, and nearby major ridges. These trends are shown by the correlations in Table 6. The characteristics of the buffer strips located further south may help to explain why they initially had better survival.

For the initial samples, the North Umpqua area suffered the greatest percentage loss due to windthrow over the winter of 1975-1976. Perhaps this is due to one buffer strip in the North Umpqua Forest losing a number of large trees over the winter. The original volume per acre (ORIGVOL) and average gross volume per tree (VOLTREE), for this particular buffer strip, were over twice the average for the North Umpqua Forest buffer strips. The loss of these large trees in one buffer strip markedly affected the over-the-winter loss for the North Umpqua Forest.

Net Timber Value of Buffer Strips and Value of Losses

To obtain a simplified estimate of buffer strip timber values, average 1976 timber sale stumpage values were multiplied by the total net timber volume in each

Table 5. Percentage Survival Comparison Between Forests

	Mt. Hood	Willamette	N. Umpqua
1975 initial sample	74.8%	87.7%	90.3%
pooled sample	80.8%	87.7%	89.3%
1976 initial sample	71.5%	82.8%	81.3%
pooled sample	59.9%	76.6%	76.9%
loss over 1975-1976 winter			
initial samples	3.3%	4.9%	9.0%
pooled samples	20.9%	11.1%	13.0%

Table 6. Simple Correlations Between Selected Variables

variables	correlation coefficient	variables	correlation coefficient
TOWNSHIP, ELEV	-0.16 NS	VOLREM, TOWNSHIP	0.14 NS
TOWNSHIP, ORIGVOL	-0.52 **	VOLREM, ELEV	-0.42 **
TOWNSHIP, VOLTREE	-0.37 *	VOLREM, ORIGVOL	-0.54 **
TOWNSHIP, DISTRIDG	-0.42 **	VOLREM, VOLTREE	-0.33 *
TOWNSHIP, UNSPECIE	-0.36 *	VOLREM, DISTRIDG	-0.30 *
TOWNSHIP, NOTALL	-0.57 **	VOLREM, UNSPECIE	-0.27 NS

significance

NS not significant

* significant at $\alpha = 0.1$

** significant at $\alpha = 0.01$

buffer strip. The values assumed were: $210/MBF for Douglas-fir, $135/MBF for western hemlock and true fir, and $130/MBF for western red cedar. A simplifying assumption was that stumpage values remained constant over the life of the buffer strip. Under these assumptions, the initial stumpage value of the trees left in the 40 buffer strips included in this study was found to be $1,072,000. Table 7 summarizes the results. Appendix 3 is a summary of the stumpage calculations for each buffer strip.

Unless salvage is undertaken, by September, 1976 this original value had been reduced to $747,000 by the combined action of windthrow, insects, disease, logging damage, and sunscald. This represents a loss of about 30 percent of the original buffer strip timber value. Douglas-fir, western hemlock, and western red cedar had from 70 to 73 percent of their original value remaining in standing buffer strips. Only 22 percent of the original true fir timber value still remains in standing buffer strips.

Buffer strips in the Mt. Hood National Forest suffered the greatest overall loss in net timber value, which amounted to about 47 percent. Both the Willamette and North Umpqua Forest buffer strips lost about 23 to 25 percent of their original net standing timber value.

Relative Windfirmness of Different Tree Species

Each tree species was windthrown at a different rate. Table 8 shows the windthrow rates for each tree species. Table 8 is broken into two parts: all buffer strips, and susceptible buffer strips. All trees were counted together to form the all buffer strips tally, while only the trees in buffer strips with a windthrow rate of 13 percent or greater were counted to form the susceptible

Table 7. Summary of Buffer Strip Values and Losses
(values represent 1000's of dollars)

	DF	WH	WRC	TF	TOTAL
Mt. Hood N.F. (pooled sample)					
initial value	146.1	62.0	31.7	17.8	257.6
as of 1976	84.7	32.2	16.4	4.5	137.1
percent loss	42	48	48	75	47
Willamette N.F. (pooled sample)					
initial value	535.8	112.6	50.1	10.6	709.1
as of 1976	404.4	82.5	40.8	1.8	529.5
percent loss	24	27	19	83	25
North Umpqua Forest (pooled sample)					
initial value	51.7	38.9	14.8	0	105.4
as of 1976	34.2	33.9	13.0	0	81.1
percent loss	34	13	12	0	23
All Forests Combined (pooled sample)					
initial value	733.6	213.5	96.6	28.4	1072.1
as of 1976	523.3	148.6	70.2	6.3	747.7
percent loss	29	30	27	73	30

Table 8. Blowdown Rates for Different Tree Species

All Buffer Strips

species	blowdown rate
Douglas-fir (DF)	22%
western hemlock (WH)	17%
western red cedar (WRC)	11%
true fir (TF)	54%

	DF	WH	WRC	TF
DF		*	*	*
WH	*		*	*
WRC	*	*		*
TF	*	*	*	

Susceptible Buffer Strips

species	blowdown rate
Douglas-fir (DF)	39%
western hemlock (WH)	37.3%
western red cedar (WRC)	27%
true fir (TF)	69.2%

	DF	WH	WRC	TF
DF			*	*
WH			*	*
WRC	*	*		*
TF	*	*	*	

*chi-square contingency table test indicates significance at $\alpha = 0.05$

buffer strips tally. The trees in each buffer strip were tallied by diameter class, height class, and condition. The results of these tallies are shown on the bar graph in Figure 10.

Overall, western red cedar was the most windfirm, followed by western hemlock, Douglas-fir, and true fir, in order of decreasing windfirmness. Chi-square contingency tables were constructed to test whether the different windthrow rates between species were significant. The right half of Table 8 is a chi-square contingency table results matrix. Asterisks indicate significantly different windthrow rates at $\alpha = 0.05$. For all buffer strips, the rate of windthrow between species was significantly different.

Past researchers found that Douglas-fir was usually the most windfirm, followed by western hemlock and western red cedar. Furthermore, in these past studies, western red cedar and western hemlock often exchange places in the windfirmness ratings, depending on the wetness of the growing site.

It is interesting to compare the windfirmness rating for all buffer strips combined, with those obtained for trees in susceptible buffer strips. For the susceptible buffer strips, western red cedar was again the most windfirm tree species followed by western hemlock, Douglas-fir, and true fir. Again, chi-square contingency tables were constructed to test whether the windthrow rates were significantly different at $\alpha = 0.05$. The results of these tests are shown in the chi-square contingency table results matrix, located in the lower right hand corner of Table 8. Western red cedar was windthrown at a significantly lower rate than the other three tree species. True fir was windthrown at a significantly higher rate than the other tree species. Douglas-fir and western hemlock were windthrown at statistically the same rate.

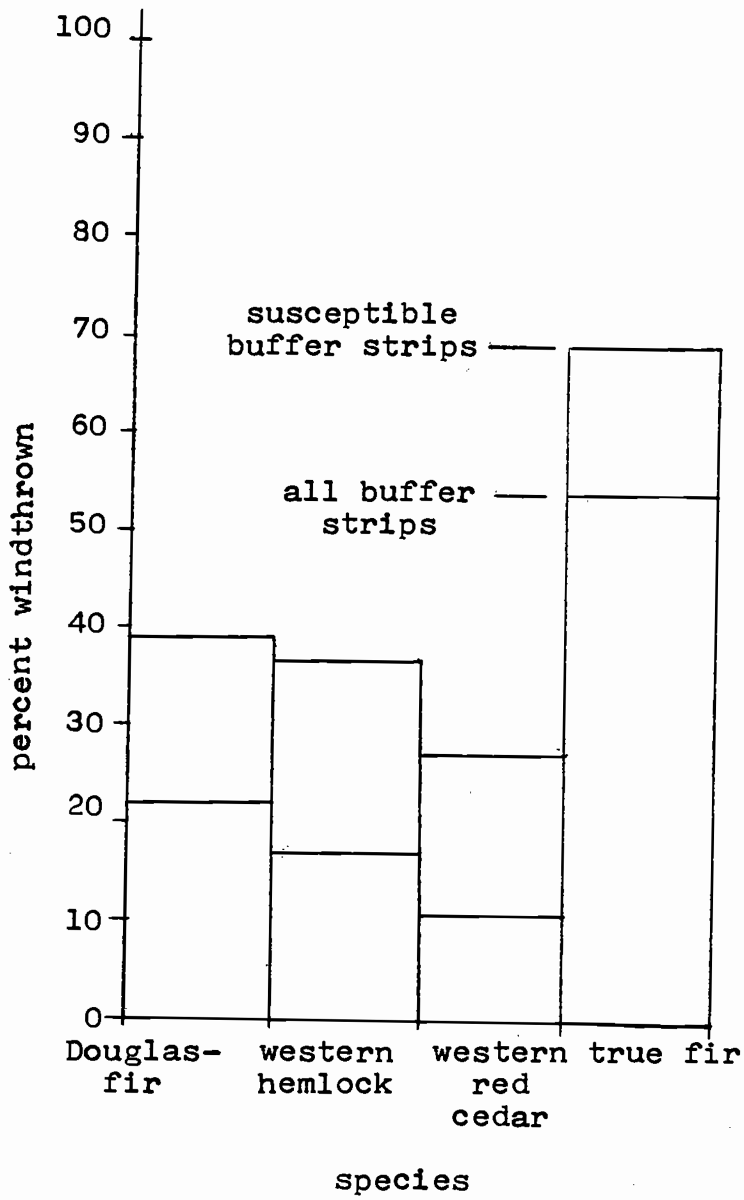


Figure 10. Percent of trees in each species windthrown in all buffer strips compared with percent windthrown in susceptible buffer strips.

Another goal of the windthrown tree tally analysis was to tabulate, by species, the number of trees originally in each diameter and height class, compared with the number of trees remaining in each diameter and height class. Again, the tabulations were made separately for all buffer strips combined and susceptible buffer strips.

Figures 11 to 18 show the results of this tabulation. In each figure, the top bar graph shows the results for all buffer strips and the lower bar graph shows the results for susceptible buffer strips.

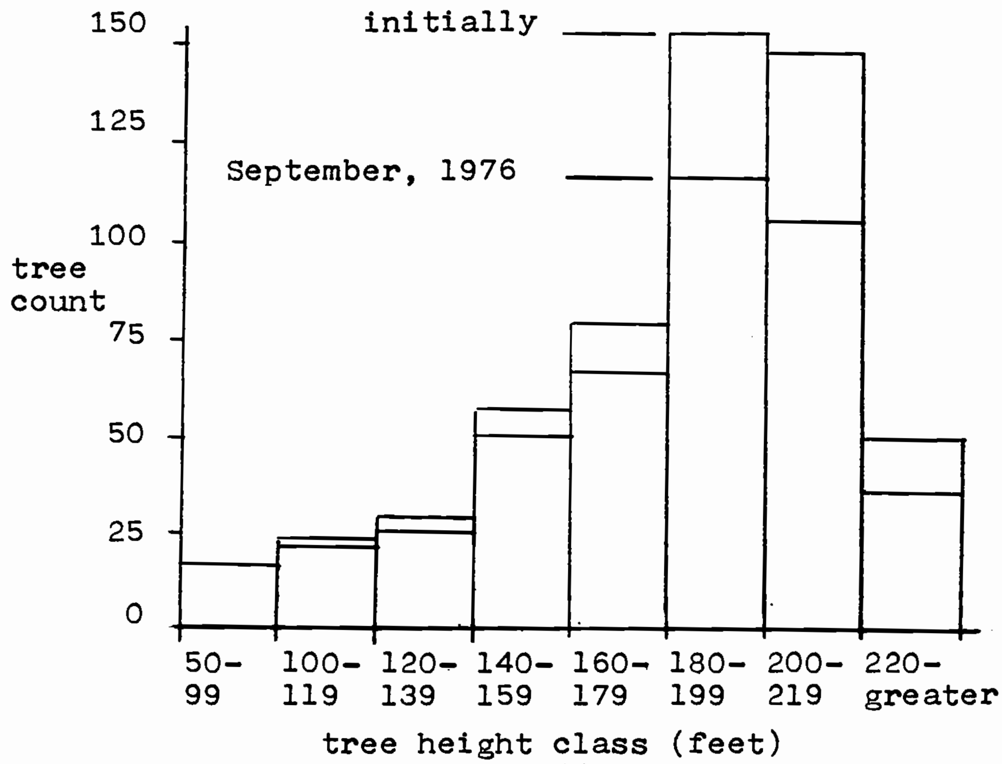
Most of the Douglas-fir trees were in the 30-50 inch diameter class and the 180-210 foot height class. These diameter and height classes were the most susceptible to windthrow for Douglas-fir. In contrast, most of the western hemlock trees were in the 10-30 inch diameter classes and the 50-140 foot height classes. The smaller diameter and shorter height classes were the least susceptible to windthrow in western hemlock. Western red cedar also tended to group in the smaller, 10-30 inch diameter class, and shorter, 50-100 foot height class. However, the most windthrown western red cedar were greater than 30 inches in diameter, and 120 feet in height. True fir were evenly spread over all height classes, but occurred most frequently in the smaller diameter classes. Small diameter true fir were the least windfirm. True fir taller than 160 feet were more windfirm than true fir shorter than 160 feet.

Chi-square contingency table tests, at the $\alpha = 0.05$ level, were used to test whether trees above or below average height or diameter were windthrown at a greater rate. The results of these tests are shown in Table 9. Again the tests were run separately for all buffer strips and susceptible buffer strips.

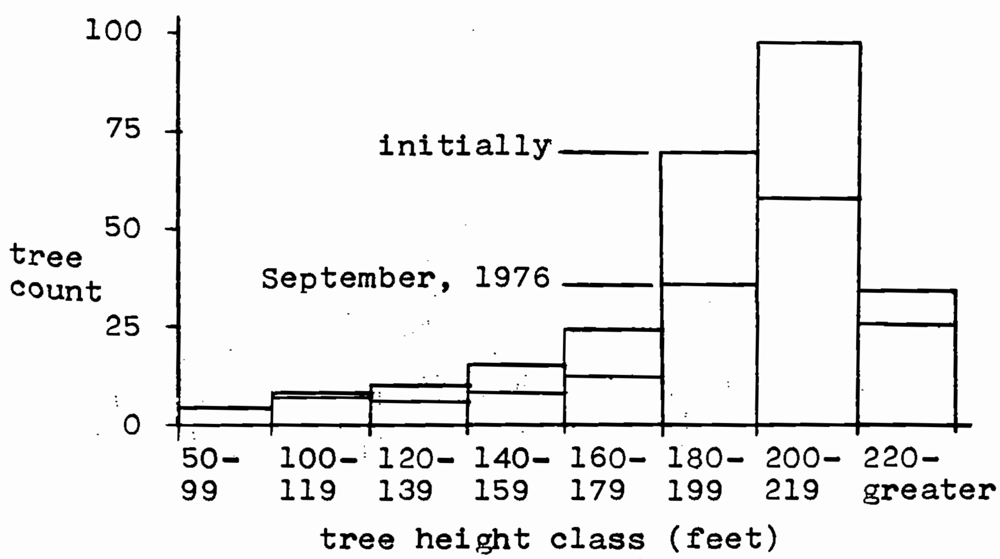
Table 9. Comparing Blowdown Rates for Trees Above and Below Average Height or Diameter

		blowdown rate				blowdown rate		
species	av. ht.	above av.	below av.		av. diam.	above av.	below av.	
all buffer strips								
Douglas-fir	180'	27%	13%	*	40"	25%	17%	*
western hemlock	110'	20%	14%	*	20"	19%	14%	*
western red cedar	120'	18%	7%	*	30"	21%	5%	*
true fir	130'	51%	57%		20"	48%	69%	
susceptible buffer strips								
Douglas-fir	180'	40%	37%		40"	40%	38%	
western hemlock	110'	43%	30%	*	20"	41%	31%	*
western red cedar	120'	32%	18%	*	30"	31%	21%	
true fir	130'	68%	69%		20"	72%	64%	

*significant difference indicated by chi-square contingency table test at $\alpha = 0.05$.

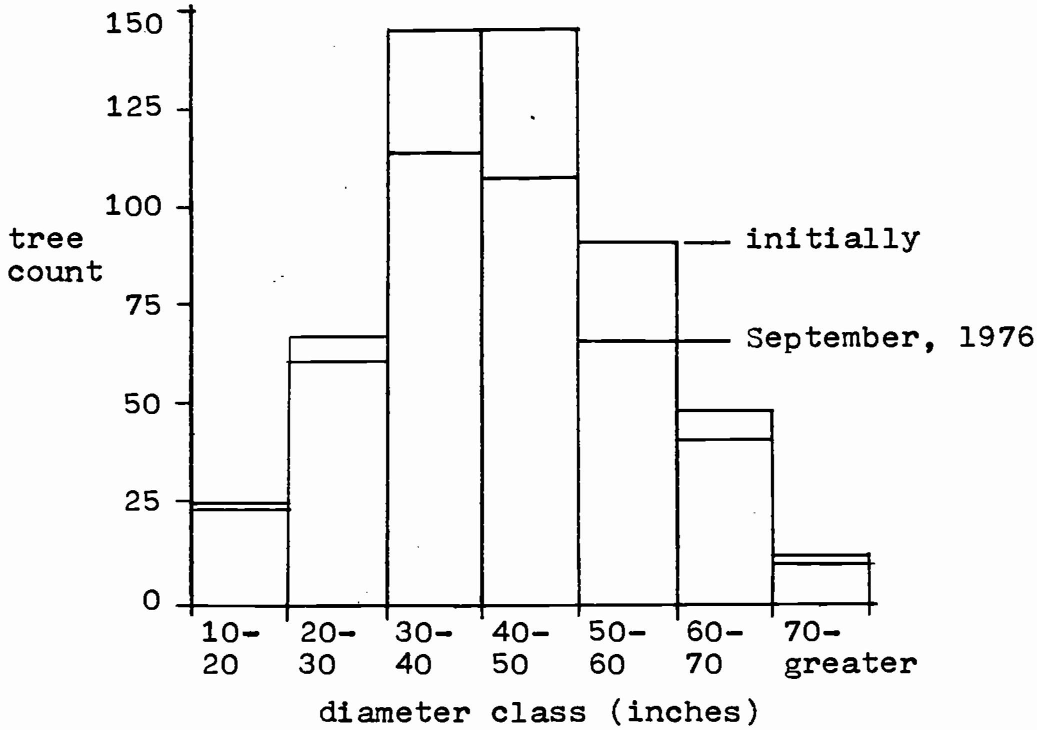


a. all buffer strips

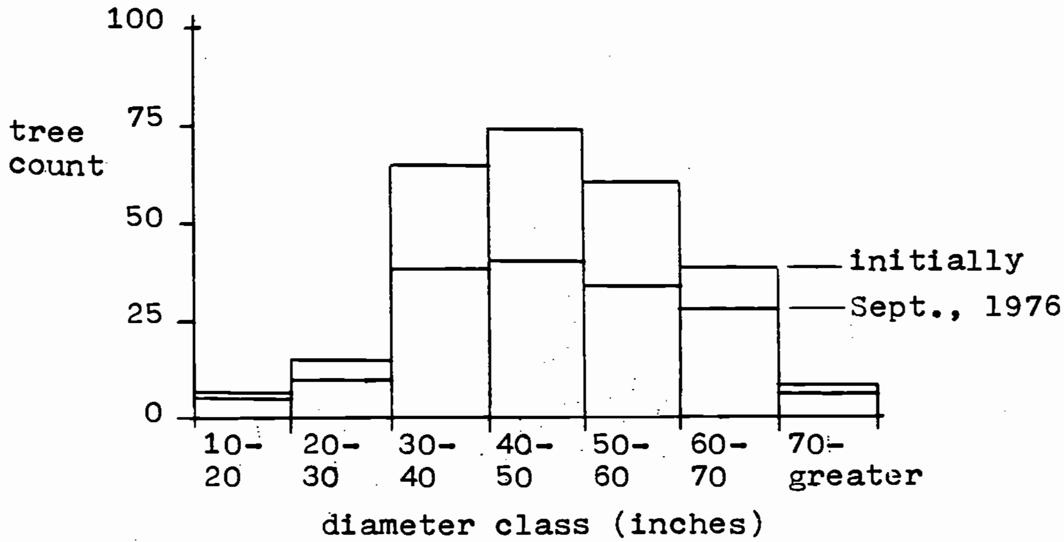


b. susceptible buffer strips

Figure 11. Number of Douglas-fir originally in each height class compared with the number remaining in each height class.



a. all buffer strips



b. susceptible buffer strips

Figure 12. Number of Douglas-fir originally in each diameter class compared with the number remaining in each diameter class.

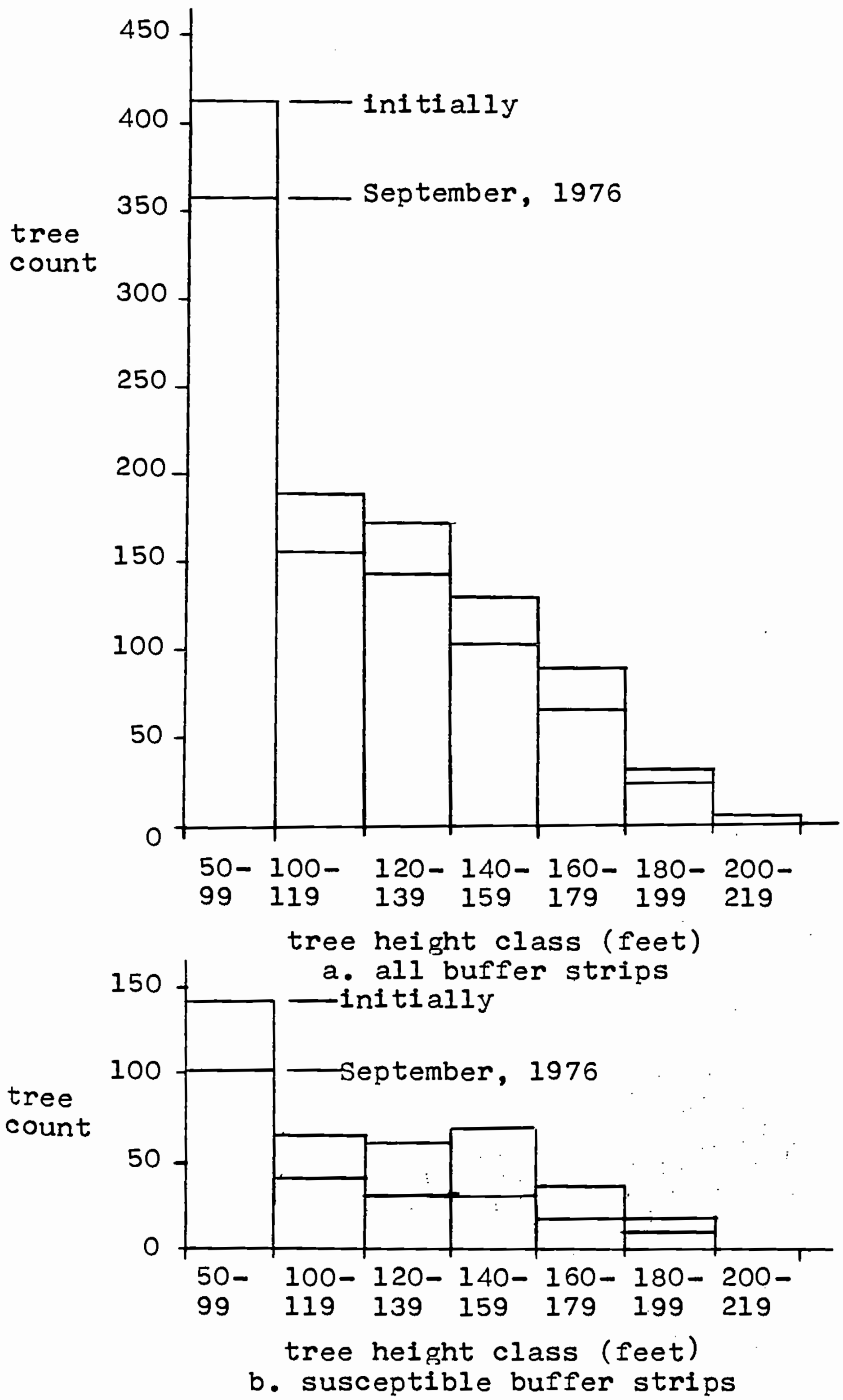


Figure 13. Number of western hemlock originally in each height class compared with the number remaining in each height class.

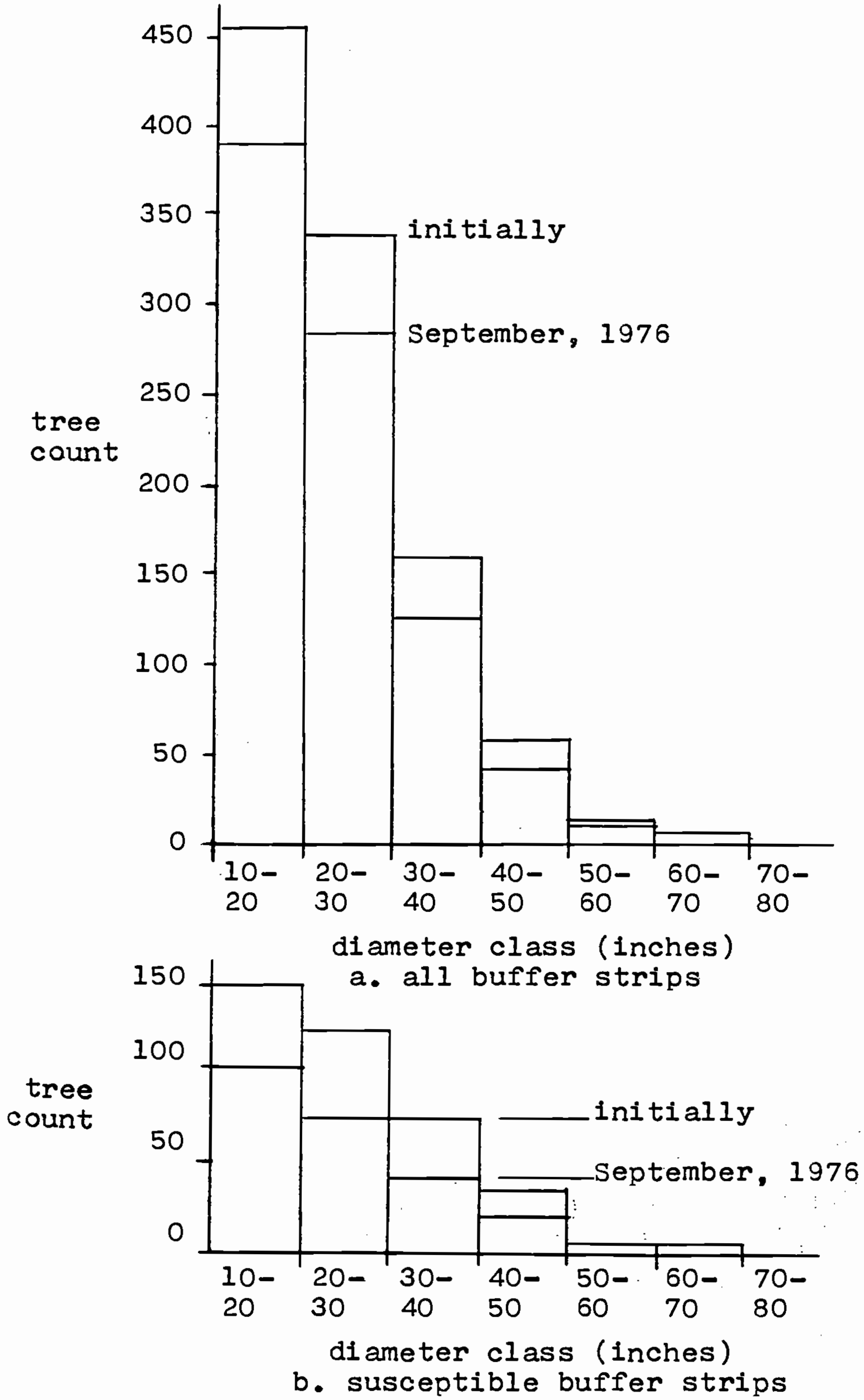


Figure 14. Number of western hemlock originally in each diameter class compared with the number remaining in each diameter class.

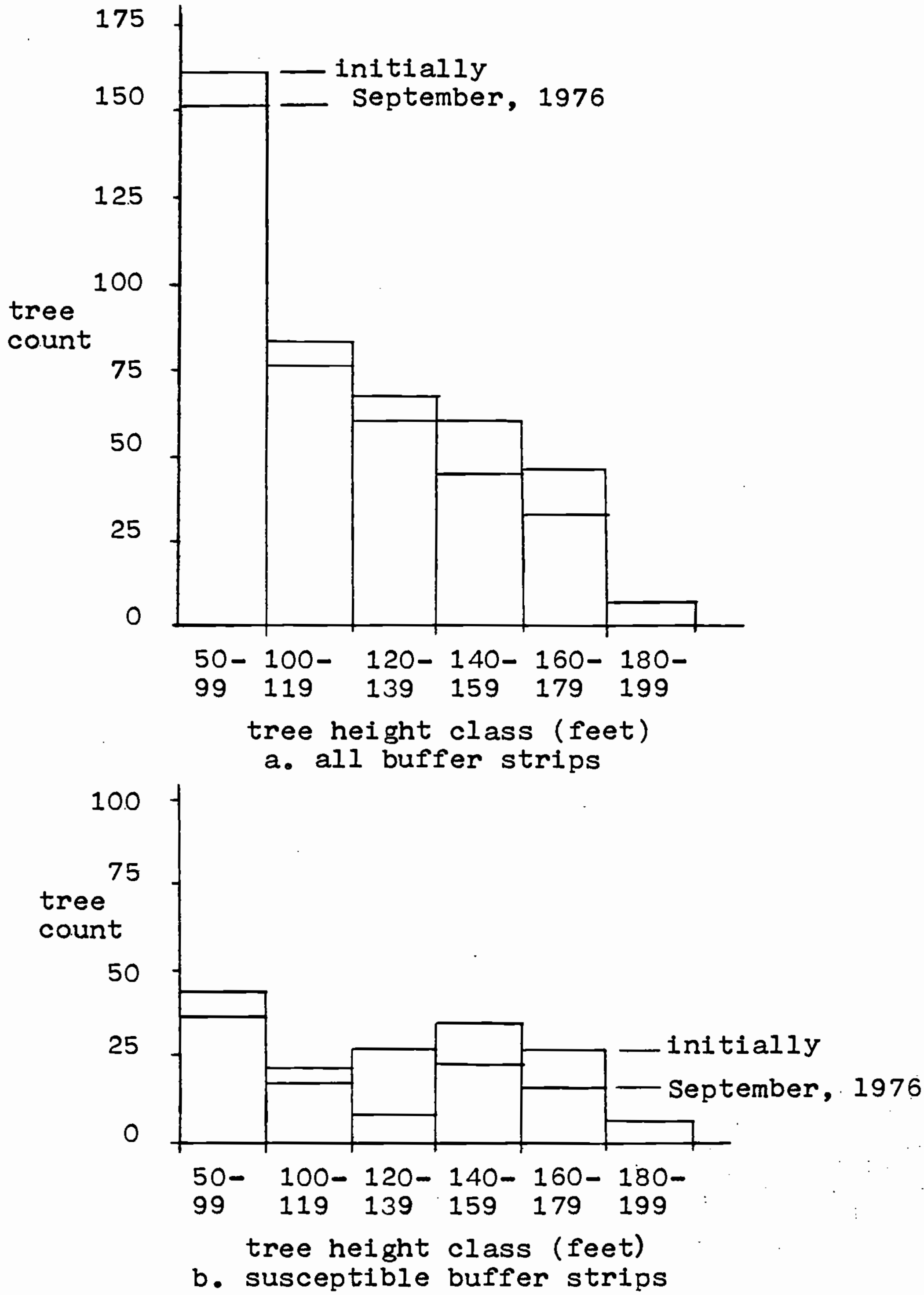
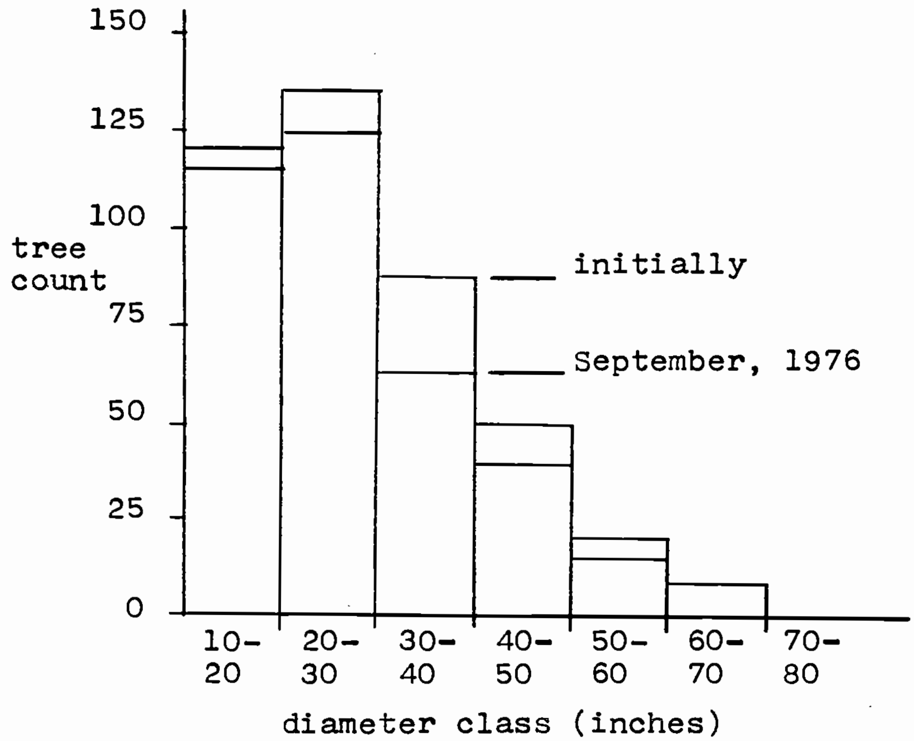
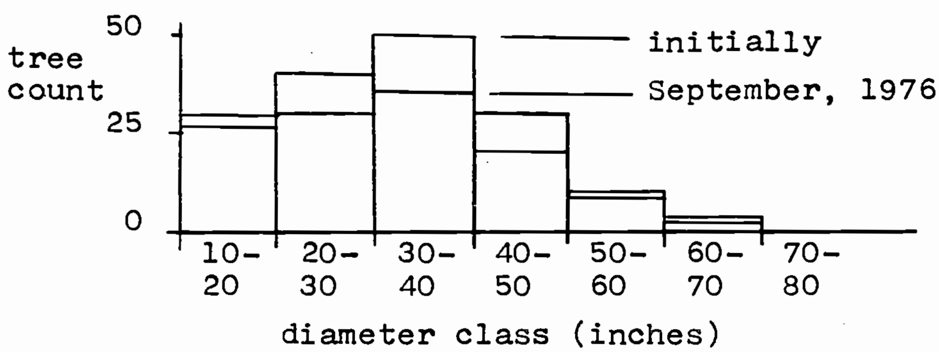


Figure 15. Number of western red cedar originally in each height class compared with the number remaining in each height class.

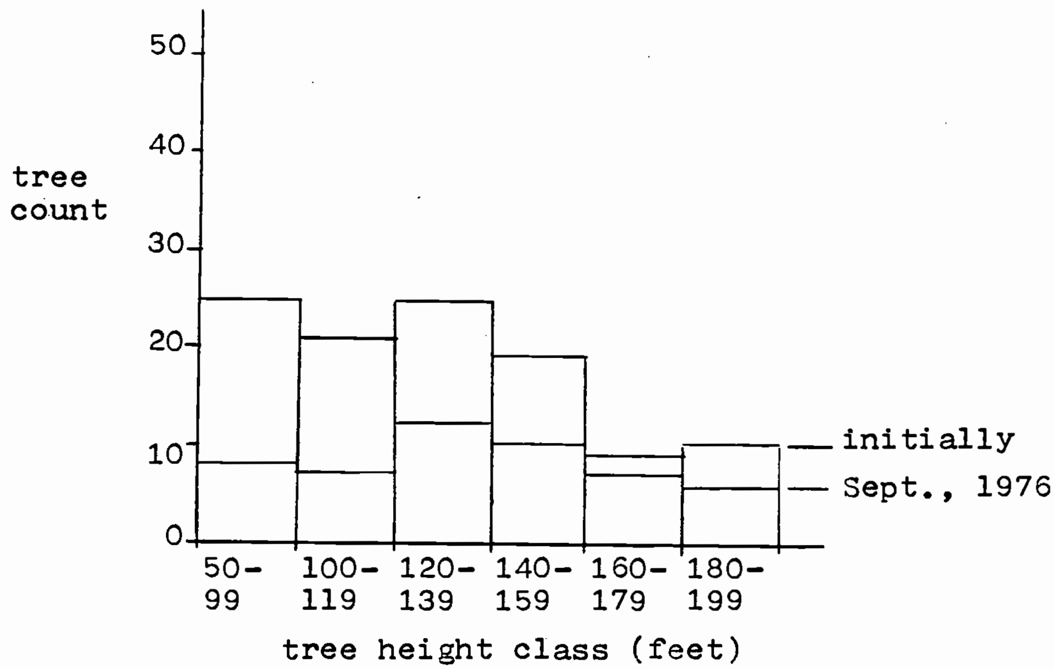


a. all buffer strips

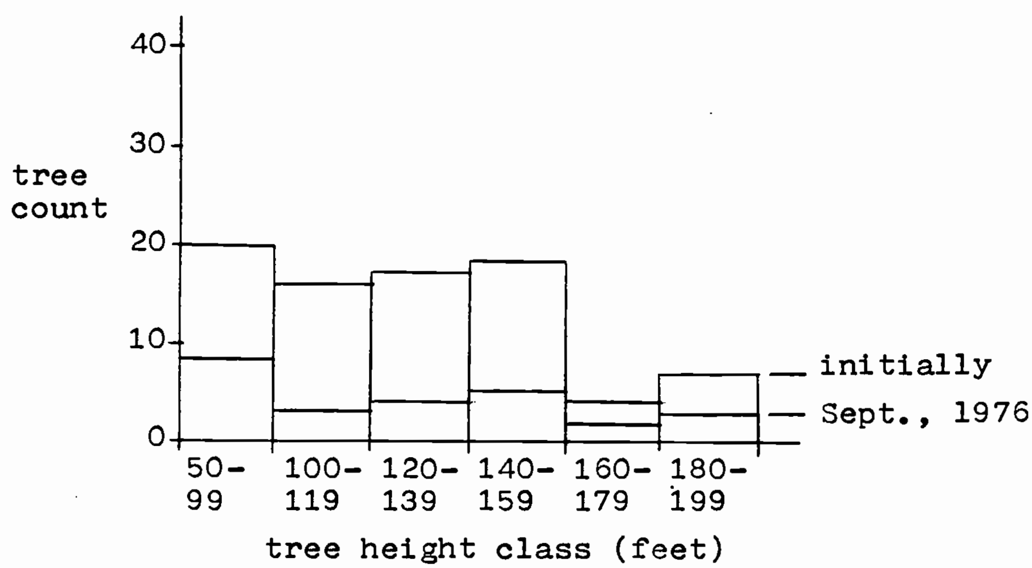


b. susceptible buffer strips

Figure 16. Number of western red cedar originally in each diameter class compared with the number remaining in each diameter class.

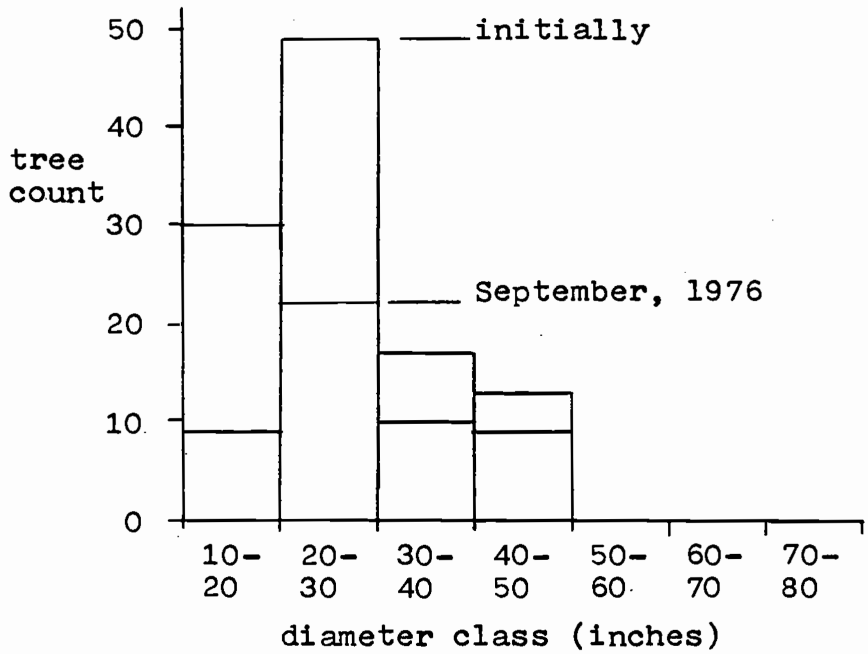


a. all buffer strips

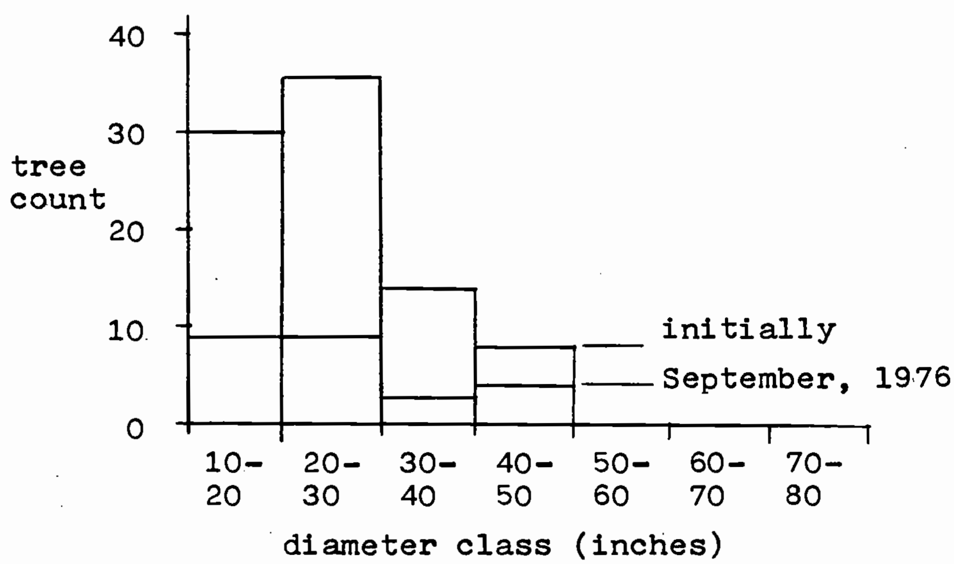


b. susceptible buffer strips

Figure 17. Number of true fir originally in each height class compared with the number remaining in each height class.



a. all buffer strips



b. susceptible buffer strips

Figure 18. Number of true fir originally in each diameter class compared with the number remaining in each diameter class.

For the all buffer strips tally, true fir above or below average height and diameter were windthrown at statistically the same rate. However, Douglas-fir, western hemlock, and western red cedar were significantly less windfirm if they had greater than average heights and diameters.

In the susceptible buffer strips, Douglas-fir or true fir above and below average height or diameter were windthrown at the same rate. Western red cedar taller than average height were significantly less windfirm, but remained equally windfirm if they were above or below average diameter. Just as for the all buffer strips tally, western hemlock greater than average height of diameter were less windfirm.

It is important to explore possible reasons for the results of the windfirmness ratings presented above. Douglas-fir, on well-drained sites, generally has a better root system than western hemlock, western red cedar, and true fir. Douglas-fir cannot tolerate shallow water tables, while western hemlock and western red cedar can adapt to shallow water tables (Minore and Smith, 1971). Generally this means that we can expect Douglas-fir growing on wet sites to have a poor root system. On the other hand, western red cedar and western hemlock are more tolerant of wetter sites and can develop better root systems.

As we can see from Figures 11 and 12, Douglas-fir trees have a tendency to group in the taller height and larger diameter classes. Western hemlock (Figures 13 and 14) and western red cedar (Figures 15 and 16) were most often in smaller diameter and height classes. Perhaps, if western hemlock and western red cedar were grouped in the larger diameter and taller height classes too, they would have had significantly greater windthrow rates.

Investigating Water Table Depth as a Possible Indicator of Survival

As described earlier in the methods section, 5 buffer strips were selected as sites for investigating the depth to the winter water table. Simple sketches of these sites are shown in Figures 19 and 20. Hardy Creek 1, Figure 20a and Cook Creek, Figure 20c, were initially selected as samples of stable buffer strips. However, after two additional winters, the Hardy Creek 1 buffer strip shows signs of steadily decreasing in stability. Winberry Creek, Figure 20b, Rider Creek, Figure 19, and Deer Creek were selected as samples of buffer strips susceptible to windthrow. The piezometers are shown as verticle lines, drawn to a scale of 1 inch equals 20 feet.

The piezometers in the Rider Creek and Winberry Creek buffer strips gave reliable readings. Water rose to within 3.6 feet of the surface of both the Winberry Creek and Rider Creek buffer strips. At the Rider Creek and Winberry Creek buffer strips, there were several windthrown trees with large root wads located near the piezometers. By sighting along the stream bank from the approximate level of water rise to the root wads of the windthrown

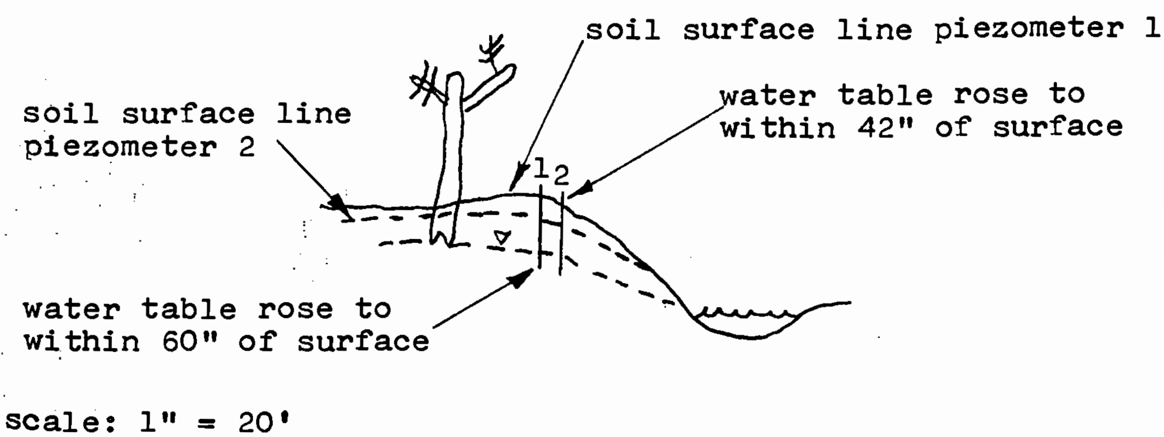


Figure 19. Rider Creek piezometers

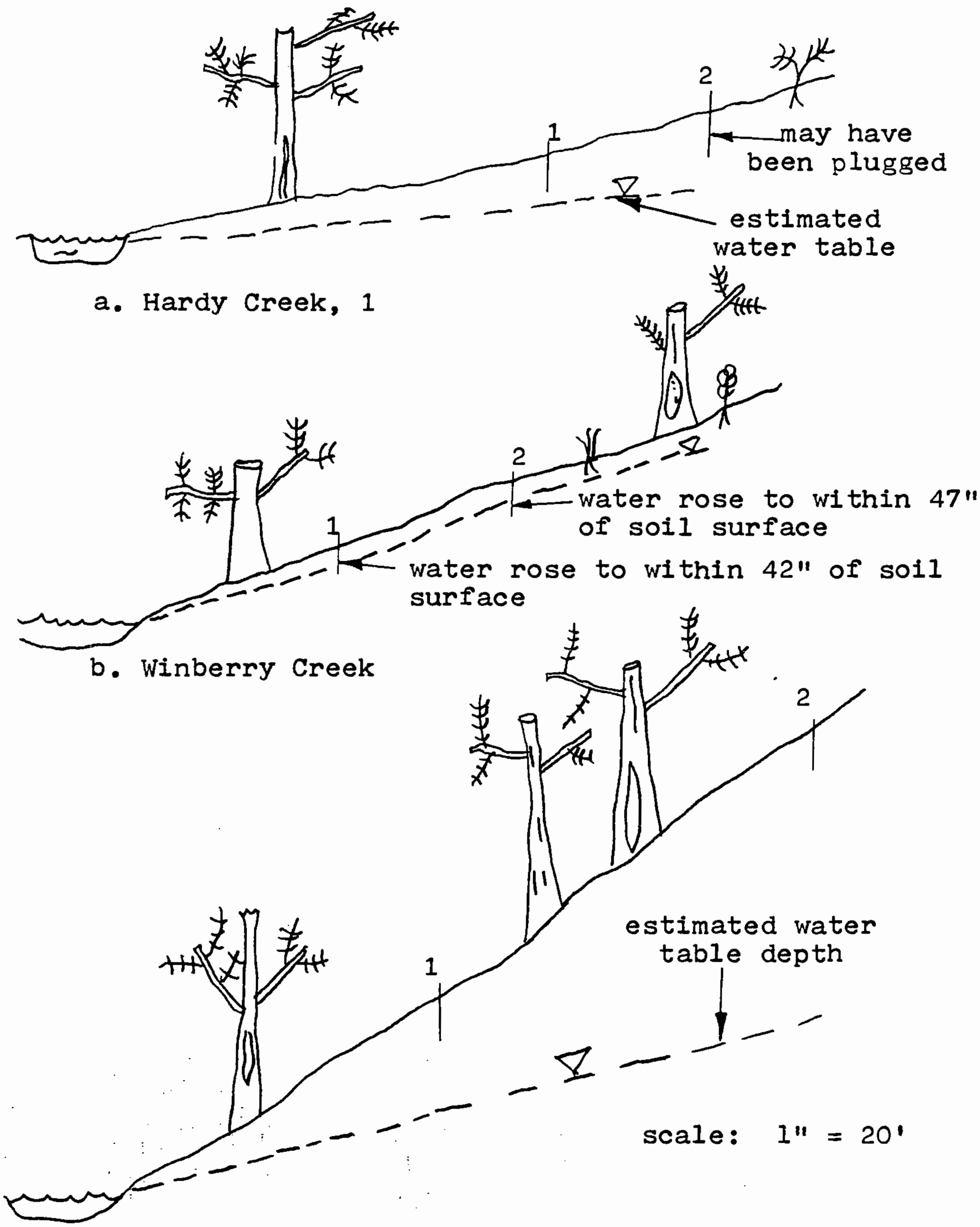


Figure 20. Piezometer location sketches

trees, it was easy to see that water had entere rooting zone of the windthrown trees. No water ro within 4 feet of the surface at the Hardy Creek 1 bu strip. Piezometer 2 did not function properly and no da was obtained. Deer Creek piezometers did not function properly and no data was obtained.

Water did not rise up into the Cook Creek piezometers. The Cook Creek buffer strip was, perhaps, one of the most stable buffer strips in this study.

None of the piezometers in the stable Cook Creek buffer strip showed any sign of water rising up into them, while piezometers in 2 out of 4 susceptible buffer strips did have water rise to within 3.5 feet of the surface. These results suggest that high water tables, entering the rooting zone, may be associated with windthrown buffer strips, while water tables in more stable buffer strips do not enter the root zone.

Water rise into the rooting zone of buffer strip trees has several implications. First, an annual high water table will restrict good deep root development. Periodically the water table may rise higher than normal into the root zone of a deeply rooted tree. The roots may eventually be killed if they are submerged for an extended period of time. Finally, saturated soils do not give the degree of root anchoring provided by drier soils.

Buffer Strip Effectiveness

An effective buffer strip shades a stream, prevents logging debris from entering the stream, and most importantly, remains standing while protecting the stream. Buffer strips left when they are not needed, especially in unstable conditions, only increase the chances of damaging the stream due to buffer strip failure. The effectiveness of each buffer strip for stream shading was measured in this study. Buffer strip effectiveness for debris blockage was not quantified. Therefore, only buffer strip effectiveness for stream shading will be described below.

<u>Stream Shading</u>

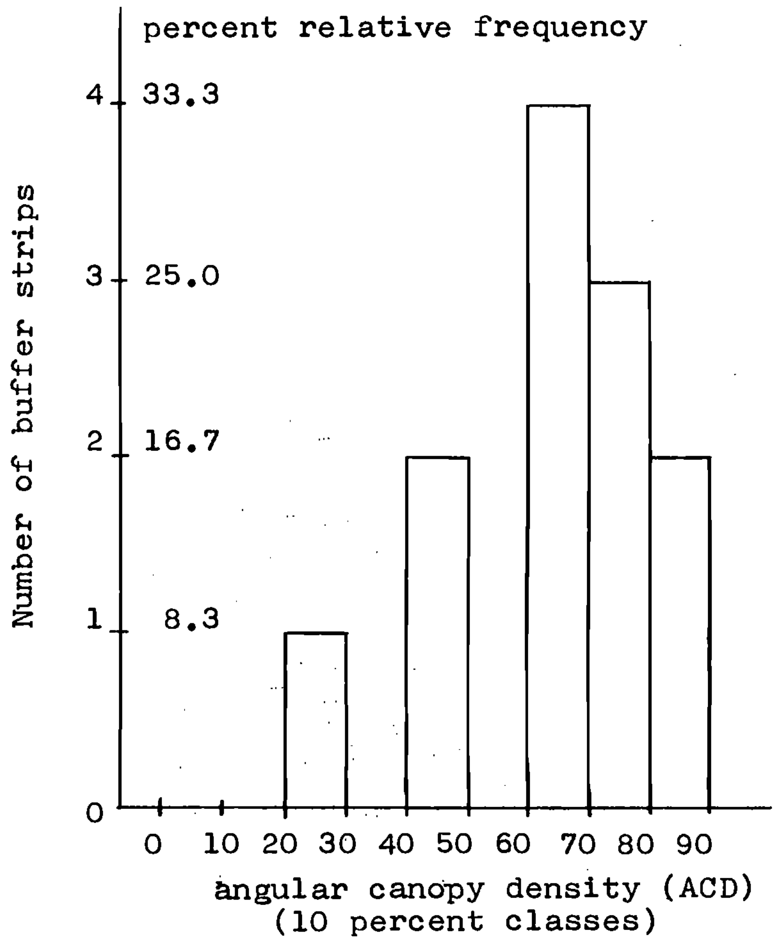
ACD, measured directly to the south, is an estimate of the ability of the canopy to shade the stream during low stream flow. In the Western Cascades, streams are most susceptible to temperature increases about August 28, when low stream flows combine with a high solar angle to produce maximum heat loads per unit volume of water.

ACD was measured for 34 streams in this study. Twenty-two streams were shaded by buffer strips and 12 were shaded by uncut timber stands.

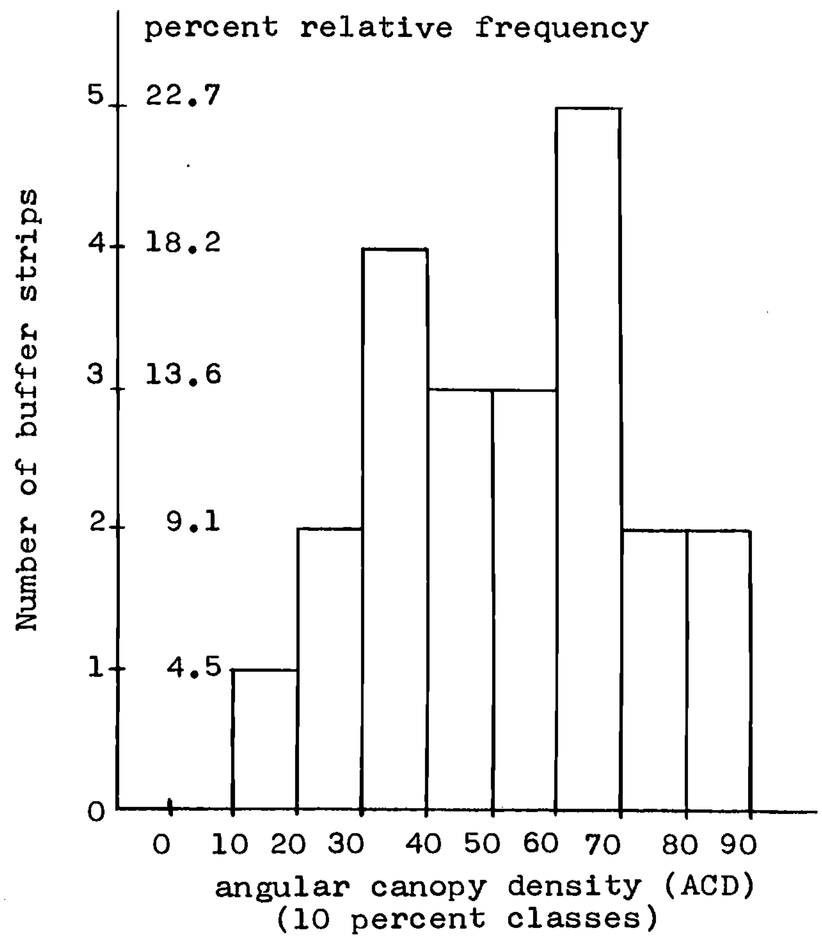
For the buffer strips, the ACD ranged from 15 to 87 percent. The results of these measurements are shown on a bar graph, Figure 21b. Sixty-eight percent of the buffer strips had ACD's between 30 and 70 percent. Eighteen percent had ACD's greater than 70 percent, while 14 percent had ACD's of less than 30 percent.

ACD under uncut stands (Figure 21a) ranged from 10 to 90 percent. Fifty percent of the uncut stands had ACD's between 30 percent and 70 percent. Forty-two percent had ACD's greater than 70 percent, while 8 percent had ACD's of less than 30 percent. It is important to notice that there is considerable variability in the ACD's for the uncut stands. Natural ACD's are different at each site, and are rarely 100 percent.

Simple correlations were run between ACD and the characteristics of the surrounding site, timber and topography. Several of the most significant correlations



a. ACD in uncut stands



b. ACD in buffer strips

Figure 21. Histograms of angular canopy density

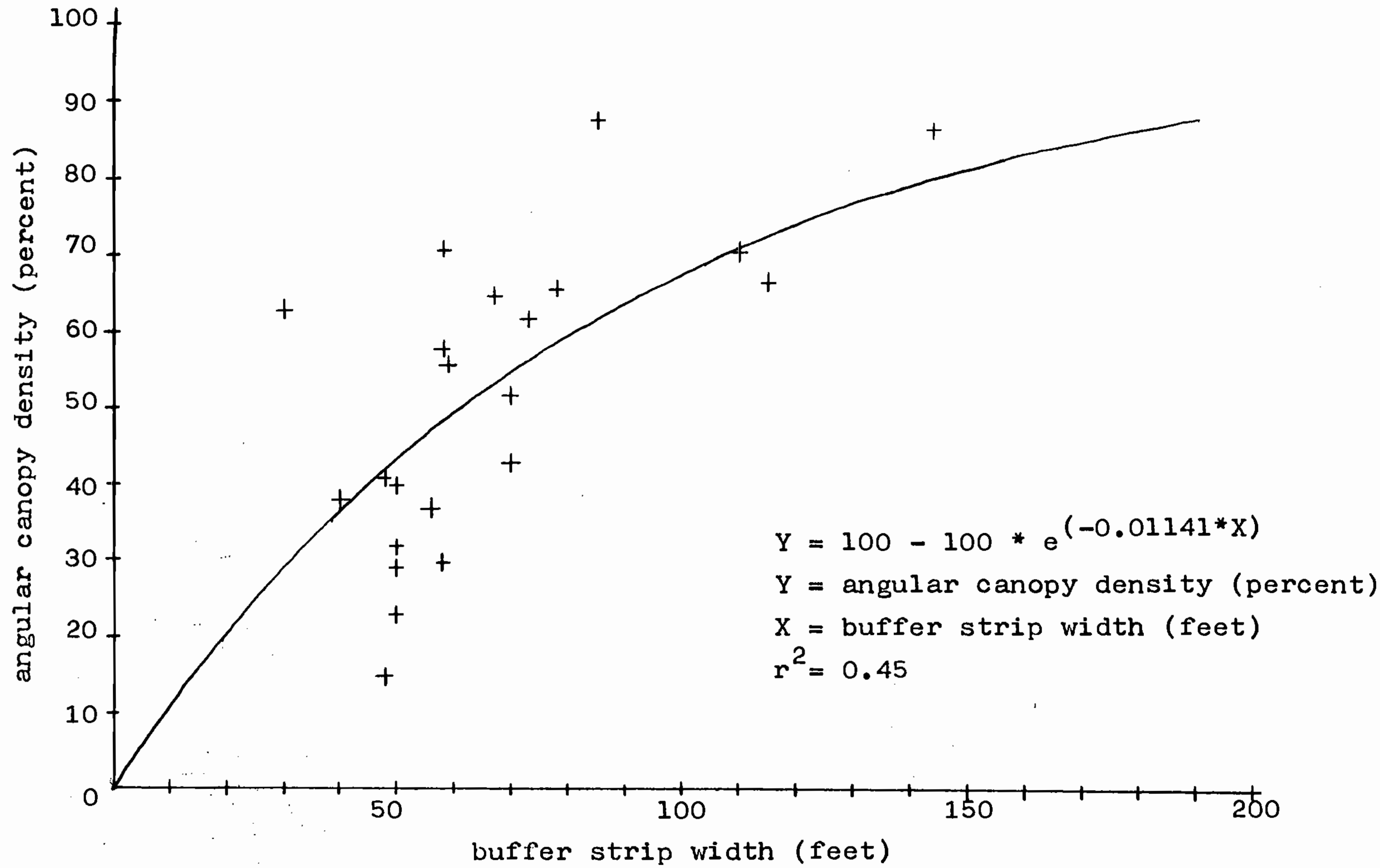


Figure 22. Non-linear regression of buffer strip width and angular canopy density

are listed below:

variables	correlation coefficient
ACD, WIDTH	0.435 *
ACD, ORIGBA	0.334 *
ACD, SLPCC	-0.540 **
ACD, UNSPECIE	0.360 NS

Significance

NS not significant
* significant at $\alpha = 0.1$
** significant at $\alpha = 0.01$

A scattergram of buffer strip width and ACD showed that the relationship between the two variables was non-linear. With the help of Dennis Dykstra, O.S.U. Forest Engineering professor, a non-linear regression was run between ACD and buffer strip width. A non-linear regression equation explained 45 percent of the variation in the sample. Other site and timber variables must account for the remaining 55 percent of the variation. A graph of the non-linear regression equation shows that for a buffer strip width of 85 feet, there is an ACD of approximately 64 percent (Figure 22). Increasing buffer strip width beyond 85 feet does not substantially increase stream shading. This is because the bulk of ACD's for uncut stands lie between 30 and 70 percent (Figure 21a), and the ACD achieved by an 85 foot wide buffer strip is close to that which can be expected under natural conditions. Seventy-five percent of the shade produced by an average natural canopy can be achieved with a buffer strip 52 feet wide.

Another significant regression model was formed with 3 other variables: SLPCRK, SLPCC, and ORIGBA. This model is shown on the next page. Although SLPCC was not significantly correlated with ACD, it became an important part of the model when combined with ORIGBA and SLPCC.

$$ACD = 27.5 + 0.0582 * ORIGBA^{*} - 0.861 * SLPCC^{**} + 0.817 * SLPCRK^{*}$$

$$R^2 = 0.561 \quad F = 8.10\ (3,19\ df)$$

<u>significance</u>

* significant at $\alpha = 0.1$
** significant at $\alpha = 0.01$

In general, this model describes how ACD increases with greater basal areas per acre (ORIGBA), and steeper slopes into the creek (SLPCRK). ACD decreases with increasing clearcut slope (SLPCC). Timber stands with greater basal areas per acre probably have greater crown densities. Steep slopes into the creek may have provided more topographic shading, as well as being covered with shade producing understory vegetation that overhangs the stream. ACD in buffer strips with steep clearcuts may have been reduced because tree crowns that would normally shade the stream were elevated above the path of incoming solar radiation. On the other hand, tree crowns on flatter clearcuts were probably more often in the path of incoming solar radiation.

Figure 23 will be used to illustrate how hardwoods, brush, and commercial trees of different heights can influence stream shading. The drawing assumes that the stream flows in an east-west direction, with the buffer strip on the south side. Overstory trees are 200 foot high Douglas-fir and 125 foot high western hemlock. The understory is sparse, except for a few large big-leaf maple (<u>Acer macrophyllum</u>), and red alder (<u>Alnus rubra</u>), which overhang the stream. The slope into the creek (SLPCRK) is 60 percent, and the clearcut slope (SLPCC) is 40 percent. Buffer strip width is 165 feet.

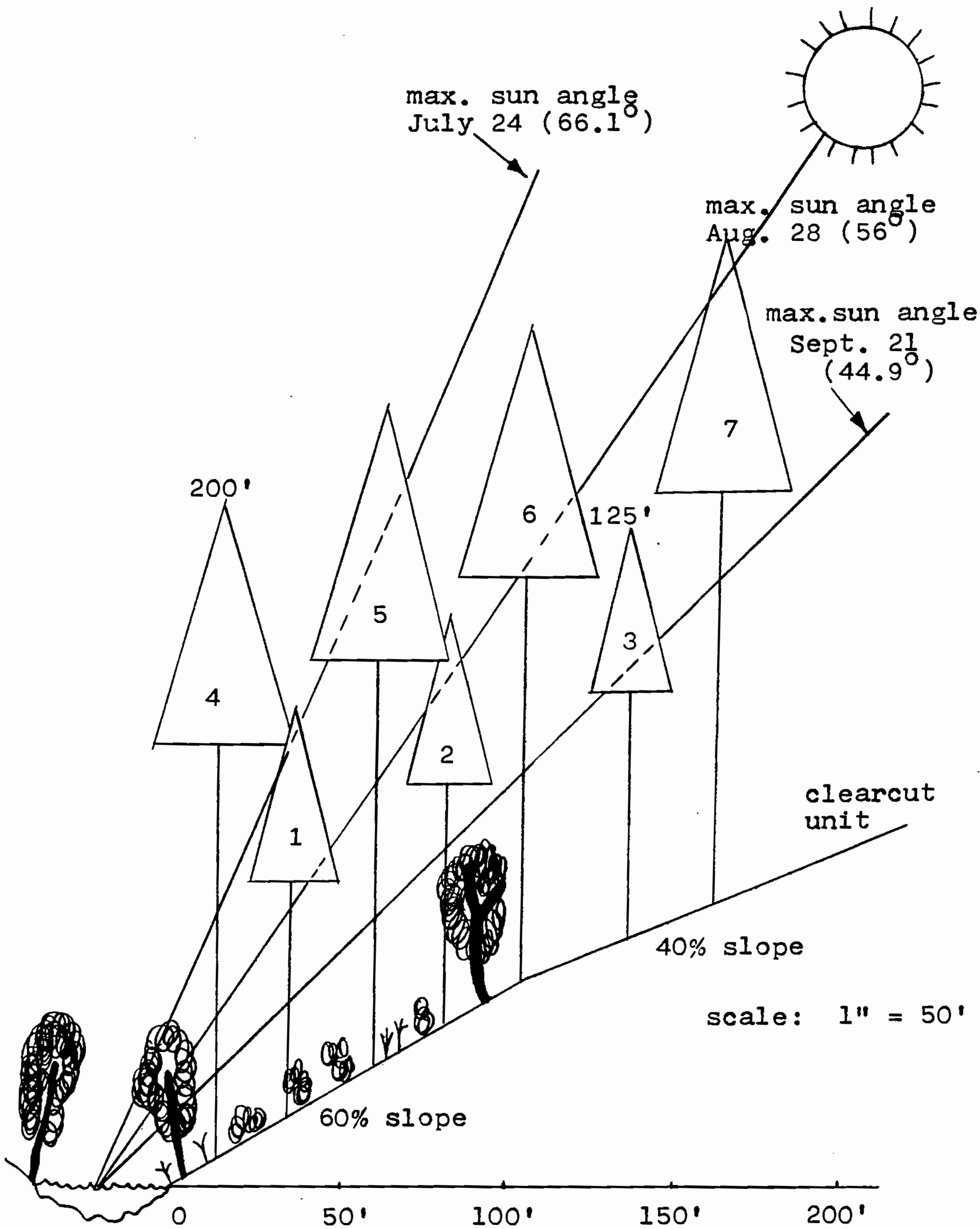


Figure 23. Stream and buffer strip cross section example. (after Froehlich, 1974)

In the middle of the stream is a point from which radiates 3 lines. From steepest to flattest, the lines represent the solar angle on July 24, August 28, and September 28, respectively. As explained earlier, the solar angle on August 28 was used for the angular canopy density measurements because when combined with low flows, the largest increases in stream temperature are likely to occur.

Figure 23 shows that all the trees are not essential for stream shading. The hardwoods and brush effectively shade the stream without any help from the remaining trees in the buffer strip. Figure 24 shows a stream completely covered by brush. Rates of regrowth of stream shading riparian vegetation are not well understood. Nevertheless, the rate of regrowth of riparian vegetation is a factor which must be considered in a stream temperature management plan for a large watershed. Planting fast growing plant species to shade the stream is another possible stream temperature management tool.

Since most streams in the Western Cascades do not have large maples or red alder overhanging the stream, other commercial trees in the buffer strip must be relied upon for stream shading until understory regrowth occurs. So, for the maximum solar angle on August 28, trees 4 and 5 do not provide much shade. Trees 4 and 5 are very tall and whatever shade they do provide is cast by their boles. The small western hemlock, trees 1, 2, and 3, would probably adequately shade the stream. An angular canopy densiometer could be used to determine which trees are actually shading the stream.

Stream orientation (ORIENT) is another factor which should be considered when designing a buffer strip. A stream running north-south will be shaded only be vegetation directly overhanging the stream, at the most

Figure 24. Brush stream shading at Lovegren Sale

critical time. Thus a buffer strip on the north side of an east-west running stream provides little stream shading.

Buffer Strip Design for Survival

— Too here

In order to effectively protect the stream, the trees in a stream buffer strip must remain standing for a number of years. Therefore, design of stream buffer strips for survival must become an integral part of the timber harvest planning process. This section will describe the design of buffer strips for wind survival.

Windthrow was identified as the major source of damage to stream buffer strips earlier in this study. Factors influencing windthrow can be divided into three groups: protection factors (topographic or uncut timber), site factors, and timber factors. These factors and their effect on windthrow will be discussed individually in the following pages. Later they will be combined into multiple regression equations, for the purpose of predicting the percentage of the original buffer strip timber volume remaining after exposure to damaging winds (VOLREM). A final section will give buffer strip survival examples and show practical applications of the multiple regression equations.

Protection Factors

Topography and nearby timber stand cutting boundaries are the most important buffer strip protection factors. Table 10 shows simple correlations between percent volume remaining in the buffer strip and the various protection factors. These correlations were made by using the pooled sample of 39 buffer strips.

The most significant individual protection variable was the distance to the cutting line in the direction of damaging winds (DISTWIND). A simple correlation between VOLREM and DISTWIND was -0.58, which means longer clearcuts in the direction of damaging winds lead to significantly greater windthrow in the buffer strip.

Determining the direction of damaging winds is an important part of designing any timber harvesting unit which includes a stream buffer strip. Winds in the Western Cascades generally come out of the southwest or east. However, it may be best to identify the direction of damaging winds at each site, as local wind turbulence may cause trees to fall in directions other than to the west or northeast.

A method of determining the direction of damaging winds is by looking for evidence of old windfalls and pits and mounds. Average direction of fall for all old

Table 10. Correlations Between VOLREM and Various Protection Factors

variables	correlation coefficient
VOLREM, DISTWIND	-0.58 **
VOLREM, DISTRIDG	-0.29 *
VOLREM, VERTHOR	0.28 *
VOLREM, EXPCODE	-0.15 *
VOLREM, SLPWIND	0.14 NS
VOLREM, SLPCRK	0.09 NS
VOLREM, SLPCC	0.08 NS
VOLREM, ELEVRIDG	-0.07 NS

significance

NS not significant
* significant at $\alpha = 0.1$
** significant at $\alpha = 0.01$

windthrown trees is a good estimate of the direction of prevailing damaging winds. Figure 25 is a photograph of old windfalls over an undisturbed section of the Bull Run River. Widespread windfall in a virgin stand or across an undisturbed section of a stream is an important clue that more windthrow can be expected if the stand is opened.

The distance to the nearest major ridge in the direction of damaging winds (DISTRIDG) was another significant protection factor. Increased distances to the nearest major ridge in the direction of damaging winds (DISTRIDG) led to significantly poorer survival. Major ridges near the stream may offer a degree of topographic shelter from damaging prevailing winds. The change in elevation from the upper edge of the buffer strip to the nearest major ridge in the direction of damaging winds (ELEVRIDG) was not, alone, significantly

Figure 25. Natural windthrow in an undisturbed section of the Bull Run River

correlated with VOLREM. However, when ELEVRIDG was included with DISTRIDG, in a multiple regression, the two variables became highly significant, and a better indicator of topographic protection than the slope factor (VERTHOR).

A slope factor, VERTHOR or (ELEVRIDG/DISTRIDG)*100, was significantly positively correlated with the percent volume remaining (VOLREM). Buffer strip clearcut units with steep slopes to the ridge would have a high VERTHOR and better survival. This suggests that winds do not adhere as well to steeper slopes, thus flowing over the buffer strip, causing less damage.

Clearcut slope (SLPCC), slope in the direction of damaging winds (SLPWIND), and slope into the creek (SLPCRK) were not significantly correlated with buffer strip survival. Perhaps they do not account for as much topographic protection as DISTRIDG and ELEVRIDG, or VERTHOR. Because a large VERTHOR, or a small DISTRIDG and large ELEVRIDG mean steep slopes to a nearby ridge, clearcut slope (SLPCC) and the slope in the direction of damaging winds (SLPWIND) are already accounted for in the regression equation. The four correlations shown below help illustrate this point. In general, the correlations mean that as the slope factor VERTHOR increases, SLPCC and SLPWIND become significantly steeper. Additionally, the correlations suggest that increasing values for DISTRIDG are associated with more gentle SLPCC and SLPWIND.

variables	correlation coefficient
VERTHOR, SLPWIND	0.70 **
VERTHOR, SLPCC	0.42 **
DISTRIDG, SLPCC	-0.41 *
DISTRIDG, SLPWIND	-0.31 *

significance	
NS	not significant
*	significant at α=0.1
**	significant at α=0.01

Exposure (EXPCODE) was defined, in this study, as exposure of the buffer strip to the east or southwest. Buffer strip exposure to damaging winds is an important factor influencing buffer strip survival, and should be carefully considered during buffer strip design. Stream buffer strips not exposed to the southwest or east had significantly better survival than buffer strips exposed to the southwest and east. Field observations indicate that buffer strips exposed to the east often had more windthrow than buffer strips exposed to the southwest.

An exposure code ranking (EXPCODE) was devised to test the significance of increasing buffer strip exposures. The codes are listed below:

1. not exposed to the southwest or east,
2. exposed to southwest,
3. exposed to east,
4. exposed to both southwest and east.

I hypothesized that increasing EXPCODE values represent increasingly hazardous buffer strip exposures. This hypothesis was proven to be true by a significant negative correlation between VOLREM and EXPCODE. Therefore, buffer strips exposed to the southwest, the east, and especially to both the southwest and east can be expected to sustain greater losses.

Saddles or dips in major ridges in the windward direction constrict prevailing winds, increasing their velocities above those blowing over a uniform ridge. Figure 26 shows a small dip or saddle in the ridge to the northeast of the Bull Run River buffer strip. Several buffer strips with this type of topographic setting had severe windthrow. Dips or saddles to the windward should be identified during field reconnaissance for a proposed timber harvesting unit. Topographic maps and aerial photographs are excellent tools for identifying these features. Finally, it is important to avoid very long distances to the cutting line in the direction of damaging winds (DISTWIND), especially if there is a dip or saddle in the major ridge. The effect of DISTWIND on potential windthrow is strongly modified by the distance to the nearest major ridge in the direction of damaging winds (DISTRIDG), and the change in elevation from the buffer strip to the top of the major ridge (ELEVRIDG). Buffer strips with more gentle slopes to the ridge or saddle will

Figure 26. Small dip or saddle in ridge to northeast of the Bull Run River buffer strip

usually have more windthrow than buffer strips with steeper slopes to the ridge or saddle.

Stream orientation (ORIENT) is a factor which explains the direction the stream is flowing, as well as the direction the clearcut is facing. Streams flowing to the northwest or southwest have a westerly aspect, while streams flowing to the northeast or southeast have an easterly aspect. For all 39 buffer strips used in the multiple regression, the simple correlation between VOLREM and ORIENT was 0.22 (not significant). For the Willamette and Mt. Hood buffer strips, the correlation between VOLREM and ORIENT was 0.31, while for the North Umpqua buffer strips it was -0.34. These correlations for the individual forest areas were significant at $\alpha=0.1$.

The windroses (Figure 8) show that most windthrow occurred from east winds in the Willamette and Mt. Hood forests and from southwest winds in the North Umpqua Forest. Buffer strips in the North Umpqua Forest survived better if their clearcut slopes faced the west, which was indicated by the negative correlation between VOLREM and ORIENT. On the other hand, buffer strips in the Mt. Hood and Willamette Forests survived better if their clearcut slopes faced the east, which was indicated by their positive correlation between VOLREM and ORIENT.

Site Factors

Site factors also play an important part in determining how well a buffer strip survives. The site factors included in this study are listed below, along with their individual correlation with percent volume remaining (VOLREM):

variables	correlation coefficient
VOLREM, SOILDPT	-0.18 NS
VOLREM, STABRATE	-0.29 *
VOLREM, UNSPECIES	-0.28 NS

significance

NS not significant
* significant at $\alpha = 0.1$
** significant at $\alpha = 0.01$

Natural stability of the buffer strip area (STABRATE) was negatively correlated with VOLREM. It shows that buffer strips on less stable sites have poorer survival. Unstable areas are sometimes associated with wet sites, which have poorly aerated soils and provide poor root anchorage.

VOLREM was slightly negatively correlated (not significant) with the understory plant species code

(UNSPECIE). The UNSPECIE coding method was probably not adequate for testing the significance of site wetness and should be improved. Field observations indicated that, almost exclusively, buffer strips with poor survival were located on wet sites. Frequently, springs or poorly drained soils were found in windthrown buffer strips. Figure 27 shows an example of a swampy area just above a windthrown buffer strip. In order to reduce the potential of windthrow, wet sites should be identified ahead of time by using plant association wetness rankings or looking for other clues such as springs and swampy areas.

In this study soils were generally gravelly loam to sandy loam in texture, with little variability among the buffer strips. Soil depth (SOILDPT), obtained from soil survey information and field observations, was not significantly correlated with VOLREM. Precise soil depth estimates at each buffer strip site would have to be made in order to obtain a more reliable correlation. SOILDPT was significantly negatively correlated with clearcut slope (SLPCC) with $r = -0.56^{**}$. This means that deeper soils were usually found on flatter slopes. Flatter slopes, in turn, offer less topographic protection.

A hardpan or unfractured bedrock layer, below well drained soils, restricts the downward movement of water and is often associated with a high water table. Severe windthrow may take place under these conditions because of the poor rooting and root anchorage resulting from a high water table.

Timber Factors

The characteristics of the timber stand are important for determining whether or not a buffer strip will be susceptible to windthrow. Several timber stand variables

Figure 27. Poorly drained soils above Bull Run River buffer strip

were measured in this study. These factors, along with their correlaions with VOLREM, are listed in Table 11.

The most important stand characteristic was WETVOL. WETVOL is an interaction variable which includes the relationship between site wetness (UNSPECIE), and original buffer strip volume per acre (ORIGVOL), and is formed by multiplying (UNSPECIE * ORIGVOL). This new interaction variable was formed to test the hypothesis that wet sites and large trees lead to increased windthrow. This theory has been stated by several prominent scientists investigating windthrow.

Table 11. Correlations Between VOLREM and Various Timber Stand Characteristics

variables	correlation coefficient
VOLREM, WETVOL	-0.56 **
VOLREM, ORIGVOL	-0.54 **
VOLREM, ORIGBA	-0.53 **
VOLREM, NOTALL	-0.45 **
VOLREM, AVHTALL	-0.39 *
VOLREM, VOLTREE	-0.34 *
VOLREM, NOSTEMS	-0.28 *
VOLREM, AVHTTALL	-0.27 *
VOLREM, NOSMALL	-0.13 NS
VOLREM, NETGROSS	0.06 NS
VOLREM, WIDTH	0.04 NS
VOLREM, OVSPECIE	-0.02 NS

significance

NS not significant
* significant at $\alpha = 0.1$
** significant at $\alpha = 0.01$

WETVOL was significantly negatively correlated with VOLREM. In other words, large trees growing on wet sites are very susceptible to windthrow, while smaller trees on drier sites are significantly less susceptible to windthrow.

Original buffer strip volume per acre (ORIGVOL), and original buffer strip basal area per acre (ORIGBA) were significantly negatively correlated with VOLREM. This means timber stands with large volumes and basal areas per acre, when exposed, are significantly more susceptible to windthrow than stands with lower volumes and smaller basal areas per acre. The original number of stems per acre (NOSTEMS) was also significantly negatively correlated with VOLREM.

Care must be taken when exposing a dense, high volume timber stand. Trees in dense stands protect each other from prevailing damaging winds, thus remaining vulnerable to wind if the trees were ever exposed. Open, low volume stands are continually exposed to wind, and develop a degree of windfirmness.

Timber stand height and volume factors were significantly negatively correlated with VOLREM. This means that as average volume per tree increased (VOLTREE), average stand height (AVHTALL) increased, average height of trees taller than 100 feet (AVHTTALL) increased, and as the number of trees taller than 160 feet/acre (NOTALL) increased, buffer strip survival was significantly poorer. Past windthrow researchers have also found that taller, large volume trees are more susceptible to windthrow.

Timber quality (NETGROSS) was not significantly correlated with VOLREM. Quality estimates were obtained from the USFS or BLM and were usually for the timber stand unit above the buffer strip. Time did not allow making a defect estimate for each tree. However, general stand defect observations were made during the volume cruise, which revealed that many windthrown trees did have butt rot and possibly even root rots. Observations indicated that trees with butt rot were also more susceptible to windsnap. A rotten portion of the tree is the weakest part, and will usually be the actual breaking point when the tree is exposed to sufficient wind force.

The overstory stand species composition should be observed when designing a stream buffer strip. Actual windthrow percentages for each tree species, tested with chi-square contingency tables, indicate that for the pooled buffer strip sample, western red cedar was the most windfirm, followed by western hemlock, Douglas-fir, and true fir, in decreasing order of windfirmness. The windfirmness ranking for the susceptible buffer strips remained the same as for the pooled sample, except that the windfirmness of Douglas-fir and western hemlock was not significantly different.

Tree root growth on steep ground must be taken into account when designing a buffer strip. On steep ground, tree roots have greater growth on the downhill side of the tree than the uphill side of the tree. In effect, the roots are acting as a buttress to hold the tree up against the force of gravity. Therefore, the tree is poorly braced for wind forces acting in a downslope direction on the uphill side of the tree. Care must be taken to avoid exposing the uphill side of the tree to severe wind forces if the tree's roots are primarily on the downhill side of the tree.

Leaving buffer strips in timber stands with jack-strawed trees generally leads to severe windthrow. The degree of exposure to damaging winds will modify the extent of wind damage in a buffer strip with jackstrawed trees. Figure 28 shows the jackstrawed, defective trees in the Elk Creek buffer strip. After 3 winters, approximately half the original timber volume was windthrown.

How does buffer strip width affect survival? This question is controversial, and is one that is often asked. The simple correlation between buffer strip width (WIDTH) and VOLREM, for all 39 buffer strips is -0.04 (not significant). Therefore, within the limits of this study buffer strip width is not an important factor influencing buffer strip survival. Clearly, certain timber, site, and topographic factors are more important than width.

Figure 28. Jackstrawed trees at Elk Creek buffer strip

Multiple Regression Equations for Predicting VOLREM

Multiple regression equations provide a means of simulating many different types of field conditions, and getting a prediction of the survival of a proposed stream buffer strip. Twenty-nine independent variables were tested in the regression analysis. Thirty-nine observations were included in the analysis.

Two regression equations were derived for each of the following areas:

1. Mt. Hood and Willamette Forest (26 obs.)
2. Willamette Forest (20 obs.)

3. North Umpqua Forest (13 obs.)
4. Pooled buffer strip sample (39 obs.)

The pooled buffer strip sample offered an opportunity to determine which factors, together, are important for predicting VOLREM over the entire sampling area. Table 12 shows multiple regression equations a and b, which were derived for the pooled sample. Both equations are significant at $\alpha = 0.01$. They include the following factors: timber factors, topographic factors, and site factors.

Essentially, both regression equations are the same. However, equation b contains the variable WETVOL, instead of ORIGVOL. The regression equation with WETVOL has a lower mean squared error and larger R^2. Generally, both equations indicate that percent volume remaining (VOLREM) is lower with the following trends:

1. longer distances to the cutting line in the direction of damaging winds (DISTWIND);
2. increasing volumes per acre on wet sites (WETVOL);
3. increasing volumes per acre (ORIGVOL);
4. less change in elevation from creek to major ridge in the direction of damaging winds (ELEVRIDG);
5. increasing distances to the nearest major ridge in the direction of damaging winds (DISTRIDG);
6. west facing harvesting units (ORIENT);
7. lower natural stability (STABRATE).

Topographic protection and distance to the cutting line in the direction of damaging winds (DISTWIND) were the most important variables. Tables 12 to 15 show the significance of each regression coefficient in each equation. ORIGVOL, in equation b, and WETVOL, in equation a, are also highly significant. Natural stability (STABRATE) and elevation at the buffer strip (ELEV) are

Table 12. Pooled Sample Regression Equations

a.

VOLREM(%)=109.0-0.0044*ELEV-0.011*DISTWIND
-4.48*STABRATE-0.0023*DISTRIDG
+7.55*ORIENT+0.012*ELEVRIDG
-0.032*WETVOL

R^2=0.744 MSE=121.04
F =12.9 ** (7,31df)

variable	percent variation	T value
constant	----	10.38 **
ELEV	1.9	-1.50 NS
DISTWIND	22.7	-5.22 **
STABRATE	2.1	-1.64 NS
DISTRIDG	7.8	-3.08 **
ORIENT	2.8	1.87 *
ELEVRIDG	9.5	3.40 **
WETVOL	11.8	-3.81 **
	58.6	

b.

VOLREM(%)=92.4-0.115*ORIGVOL
+0.36*VERTHOR-0.0093*DISTWIND
-6.71*STABRATE+8.57*ORIENT

R^2=0.676 MSE=143.98
F =13.8 ** (5,33df)

variable	percent variation	T value
constant	----	10.50 **
ORIGVOL	12.5	-3.58 **
VERTHOR	11.3	3.40 **
DISTWIND	16.8	-4.15 **
STABRATE	4.9	-2.24 *
ORIENT	4.3	2.10 *
	49.8	

significance levels

NS not significant
* significant at α= 0.1
** significant at α= 0.01

significant at a low level, but improve the accuracy of the model if they are included.

Tables 12 to 15 also provide an indication of the percent variation in the regression explained by each variable. These values are shown directly beneath the column heading of percent variation, and represent the amount of variation explained by a variable in the model, given the other variables are already in the equation. If the percentages of variation add up to, or are near the R^2, then the variables are relatively independent. If the sum is less than the R^2, then some of the variation must be explained by interaction among the variables.

Equation a, Table 13, is the same as equation a, Table 12, but was derived for only the Willamette and Mt. Hood National Forests combined. Similarly, equation b, Table 13, is the same as equation b, Table 12. Both equations are better predictive models than those for the pooled sample. This is probably because the samples are less variable. All observations about equations in Table 12 also apply to equations in Table 13. However, the variable ORIENT is considerably more significant, indicating that buffer strips in the Willamette and Mt. Hood forests on west slopes are more susceptible to windthrow.

Multiple regression equation a, Table 14, and regression equation b, Table 14, contain the same variables as the previous equations. Because the observations used to derive Table 14 equations are all within the Willamette Forest, they are less variable, and form a better predictive model. All remarks about equations in Table 13 hold for the equations in Table 14, except for the following:

1. DISTWIND and other topographic protection factors are more important;

Table 13. Willamette and Mt. Hood Forest Regression Equations

1.5, 5-9-79

a.

.012 x DISTWIND

VOLREM(%)=90.0-0.12*DISTWIND
-5.5*STABRATE-0.0023*DISTRIDG
+17.8*ORIENT+0.013*ELEVRIDG
-0.041*WETVOL

R^2=0.818 MSE=115.4
F=14.24** (6,19df)

variable	percent variation	T value
constant	----	8.77 **
DISTWIND	21.4	-4.73 **
STABRATE	3.1	-1.79 *
DISTRIDG	8.2	-2.93 **
ORIENT	12.3	3.57 **
ELEVRIDG	12.1	3.56 **
WETVOL	19.6	-4.52 **
	76.7	

b.

VOLREM(%)=97.7-0.17*ORIGVOL
-0.01*DISTWIND-6.51*STABRATE
-0.0027*DISTRIDG+16.7*ORIENT
+0.0136*ELEVRIDG

R^2=0.783 MSE=138.0
F=11.39** (6,19df)

variable	percent variation	T value
constant	----	8.00 **
ORIGVOL	16.1	-3.74 **
DISTWIND	14.4	-3.55 **
STABRATE	4.2	-1.91 *
DISTRIDG	11.0	-3.09 **
ORIENT	10.7	3.05 **
ELEVRIDG	13.0	3.36 **
	69.4	

significance

NS not significant
* significant at $\alpha = 0.1$
** significant at $\alpha = 0.01$

Table 14. Willamette National Forest Regression Equations

a.

VOLREM(%)=81.1-0.013*DISTWIND
-0.0030*DISTRIDG+17.5*ORIENT
+0.013*ELEVRIDG-0.03*WETVOL

R^2=0.865 MSE=65.96
F =17.99 ** (5,14df)

variable	percent variation	T value
constant	----	10.79 **
DISTWIND	44.4	-6.79 **
DISTRIDG	17.3	-4.46 **
ORIENT	13.6	4.01 **
ELEVRIDG	16.9	4.42 **
WETVOL	6.8	-3.02 **
	99.0	

b.

VOLREM(%)=88.3-0.105*ORIGVOL
-0.0113*DISTWIND-3.1*STABRATE
-0.0032*DISTRIDG+15.5*ORIENT
+0.014*ELEVRIDG

R^2=0.846 MSE=81.46
F =11.86 ** (6,13df)

variable	percent variation	T value
constant	****	9.12 **
ORIGVOL	6.0	-2.24 **
DISTWIND	26.5	-4.72 **
STABRATE	1.5	-1.12 NS
DISTRIDG	20.8	-4.18 **
ORIENT	12.9	3.30 **
ELEVRIDG	20.3	4.13 **
	88.0	

significance

NS not significant

** significant at $\alpha = 0.01$

Table 15. North Umpqua Forest Regression Equations

a.

VOLREM(%)=155.8-0.377*AVHTALL
-0.0086*DISTWIND-11.3*ORIENT

R^2=0.854 MSE=32.29
F =17.51 ** (3,9df)

variable	percent variation	T value
constant	----	13.55 **
AVHTALL	24.5	-3.79 **
DISTWIND	33.5	-4.52 **
ORIENT	17.9	-3.28 **
	75.9	

b.

VOLREM(%)=116.2-0.013*ELEV+0.54*NETGROSS
-0.281*ORIGVOL+0.18*VERTHOR
-0.008*DISTWIND-9.3*UNSPECIE

R^2=0.95 MSE=16.55
F =19.0 ** (6,6df)

variable	percent variation	T value
constant	----	9.03 **
ELEV	17.3	-4.56 **
NETGROSS	10.3	3.51 **
ORIGVOL	21.6	-5.10 **
VERTHOR	4.9	2.40 *
DISTWIND	24.3	-5.39 **
UNSPECIE	9.4	-3.35 **
	87.8	

significance

NS not significant
* significant at $\alpha = 0.1$
** significant at $\alpha = 0.01$

2. ORIGVOL and WETVOL are less important.

Several observations about the variables important in the Mt. Hood Forest can be made by noting the differences in the Mt. Hood and Willamette Forest regression equations and the regression equations for the Willamette Forest by itself. ORIGVOL and WETVOL are not as important in the Willamette Forest equations as they are in the Willamette and Mt. Hood equations combined. Therefore, ORIGVOL and WETVOL must be more important for the Mt. Hood Forest buffer strips. The distance to the cutting line in the direction of damaging winds (DISTWIND) is more important in the equations for the Willamette Forest alone than for the Willamette and Mt. Hood Forests combined.

Equation a, Table 15, and equation b, Table 15, were derived for the North Umpqua area buffer strips. Both equations are very significant. DISTWIND is the most significant variable, followed by average height of all trees (AVHTALL), and stream orientation (ORIENT). Eighty-five percent of the variability in survival is associated with these 3 variables. In general, this equation means that buffer strips have poorer survival with long distances to the cutting line in the direction of damaging winds, tall trees, and east facing slopes.

Equation b has a lower mean squared error and higher R^2 than equation a. Distance to the cutting line in the direction of damaging winds is again the most important variable. Original volume per acre (ORIGVOL) is almost as important, followed by creek elevation (ELEV), timber quality (NETGROSS), stream orientation (ORIENT), and VERTHOR. The equation shows that high volumes per acre, poor quality trees, higher elevations, east facing slopes, wet sites, distant major ridges, and long cutting lines in the direction of damaging winds lead to poorer survival.

The regression equations described above are relatively simple, and contain variables that are inexpensive to obtain. Most of the variables can be simply taken from topographic maps and timber cruises. A field check of the potential buffer strip site is needed for the remaining 2 variables: site wetness (UNSPECIE), and natural stability (STABRATE).

Buffer Strip Survival Examples and Application of Regression Equations

Forty buffer strips were examined in this study. The survival of four of these buffer strips will be examined in some detail. Two of these survival examples will be used to illustrate the application of the multiple regression equations.

Example 1: Black Creek Buffer Strip (7 winters)

The section of the Black Creek buffer strip measured in this study had almost no mortality due to windthrow. Figure 29 shows a plan and profile view of the Black Creek buffer strip area. The original timber volume per acre (ORIGVOL), and overstory stand species composition (OVSPECIE) are about average for the Willamette and Mt. Hood National Forests. The site is wetter than average (UNSPECIE), stand density (NOSTEMS), is greater than average, but average tree volume (VOLTREE) is less than average.

This buffer strip has one outstanding feature: excellent topographic and uncut timber stand protection. An uncut stand shelters the buffer strip from east winds, and excellent topographic protection shelters the buffer strip from southwest winds. Profile 1, Figure 29, shows

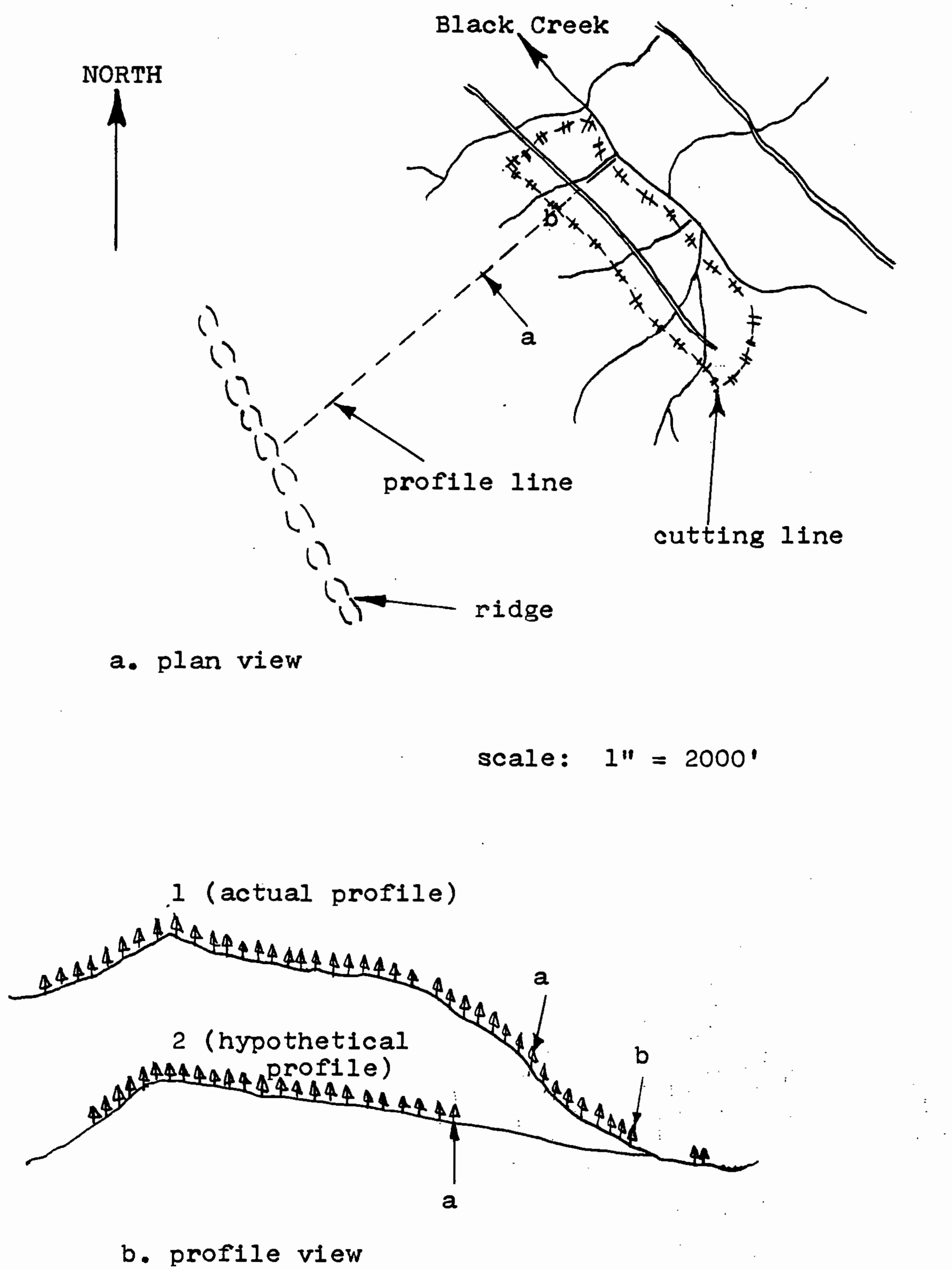


Figure 29. Plan and profile view of Black Creek buffer strip.

the topographic protection to the southwest of the buffer strip. The distance to the cutting boundary in the direction of damaging winds is less than average (DISTWIND), distance to the ridge to the southwest is average (DISTRIDG), but the change in elevation from the buffer strip to the ridge (ELEVRIDG) is over twice average.

Suppose for Profile 1, that the cutting line is at a, instead of b. DISTWIND is now 2275 feet instead of 735 feet. Using equation a, Table 14, VOLREM is now 75.5 percent instead of the 100 percent with the 735 feet DISTWIND. The estimated and predicted VOLREM is shown along with confidence intervals in Figure 30.

Profile 2 is a hypothetical profile with very poor topographic protection. DISTRIDG is still the same, but ELEVRIDG is now 1000 feet. DISTWIND is now 3000 feet. Again by using equation a, Table 14, the predicted VOLREM is now 46.0 percent. Figure 30 shows the confidence intervals. Two different confidence intervals are shown in Figure 30. Prediction confidence intervals are wider than the intervals for estimation. The prediction interval gives the confidence limits for the very next buffer strip designed, while the estimation interval gives the confidence limits for designing a large number of buffer strips with the same characteristics.

Example 2: North Fork Bull Run River Buffer Strip (8 winters)

The sampled section of the North Fork Bull Run River buffer strip had very good survival. None of the trees in the sampled section of the buffer strip were lost due to windthrow after 8 years. Figure 31 shows a plan and profile view of the North Fork Bull Run River buffer strip. At the head of the buffer strip, at the bottom of clearcut

DISTWIND	2275.0	feet
DISTRIDG	4900.0	feet
ELEVRIDG	2499.0	feet
WETVOL	375.0	
ORIENT	1	

VOLREM (new) = 75.6 percent

<u>Estimation Limits</u>

95% (64.7 percent, 86.7 percent)
99% (60.4 percent, 90.9 percent)

<u>Prediction Limits</u>

95% (55.0 percent, 96.1 percent)
99% (47.0 percent, 104.0 percent)

a. Black Creek actual profile

DISTWIND	3000.0	feet
DISTRIDG	4900.0	feet
ELEVRIDG	1000.0	feet
WETVOL	375.0	
ORIENT	1	

VOLREM (new) = 46.0 percent

<u>Estimation Limits</u>

95% (35.5 percent, 56.4 percent)
99% (31.5 percent, 60.5 percent)

<u>Prediction Limits</u>

95% (25.7 percent, 66.3 percent)
99% (17.8 percent, 74.2 percent)

b. Black Creek hypothetical profile

Figure 30. Black Creek survival prediction examples.

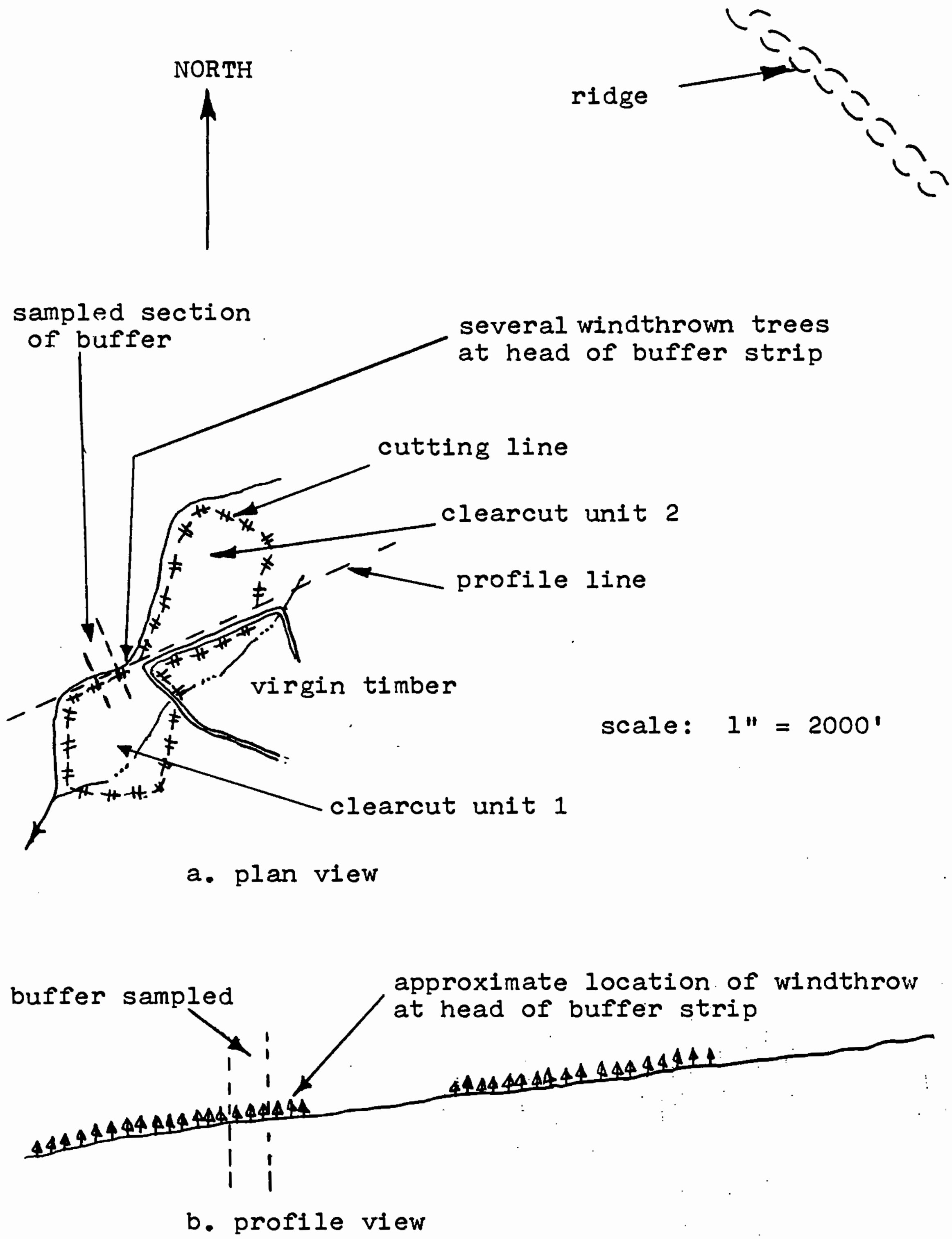


Figure 31. Plan and profile view of North Fork Bull Run River buffer strip.

unit 2, there were a number of windthrown trees.

Timber volume per acre (ORIGVOL), original number of stems per acre (NOSTEMS), and average volume per tree (VOLTREE) were less than average. The old growth stand is decadent, on a very wet site, and has more western hemlock and true fir than average.

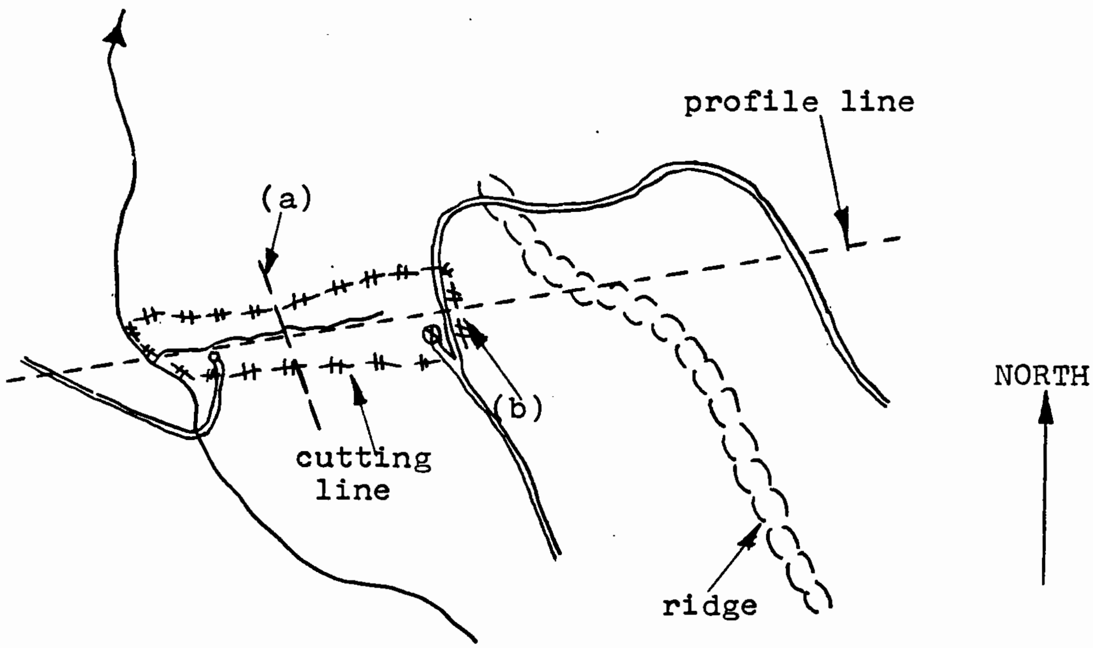
The buffer strip is oriented to the northeast, almost parallel to the direction from which the prevailing winds blow. Uncut timber to the east and southwest shelter the buffer strip. In contrast, the windthrown trees at the head of the buffer strip are located in the lower corner of unit 2, with exposure to the NE for 1600 feet.

Example 3: Davey Creek Buffer Strip (3 winters)

After 3 winters, almost half of the original timber volume was windthrown in the Davey Creek buffer strip. Natural stability in the area is low, original timber volume per acre (ORIGVOL) is average, but the number of stems/acre (NOSTEMS) is greater than average. Average volume per tree (VOLTREE) is less than average. Plant species found in the area indicate that the site has average moisture conditions. About 1/3 of the original stand volume is true fir, the species found to be least windfirm in this study.

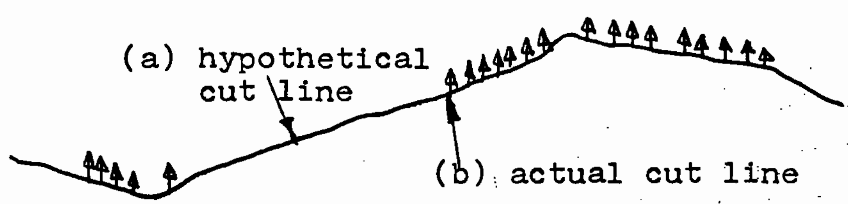
Distance in the direction of damaging winds (DISTWIND) was three times average, while the distance to the ridge in the direction of damaging winds (DISTRIDG) was average. However, the change in elevation from the buffer strip to the major ridge (ELEVRIDG) was above average.

Figure 32 shows a plan and profile view of the buffer strip, and Figure 33 shows a larger scale view of the buffer strip. After the second winter, most of the blowdown was in the corner of the buffer strip, shown in



a. plan view

scale: 1" = 2000'



b. profile view

Figure 32. Plan and profile view of Davey Creek buffer strip.

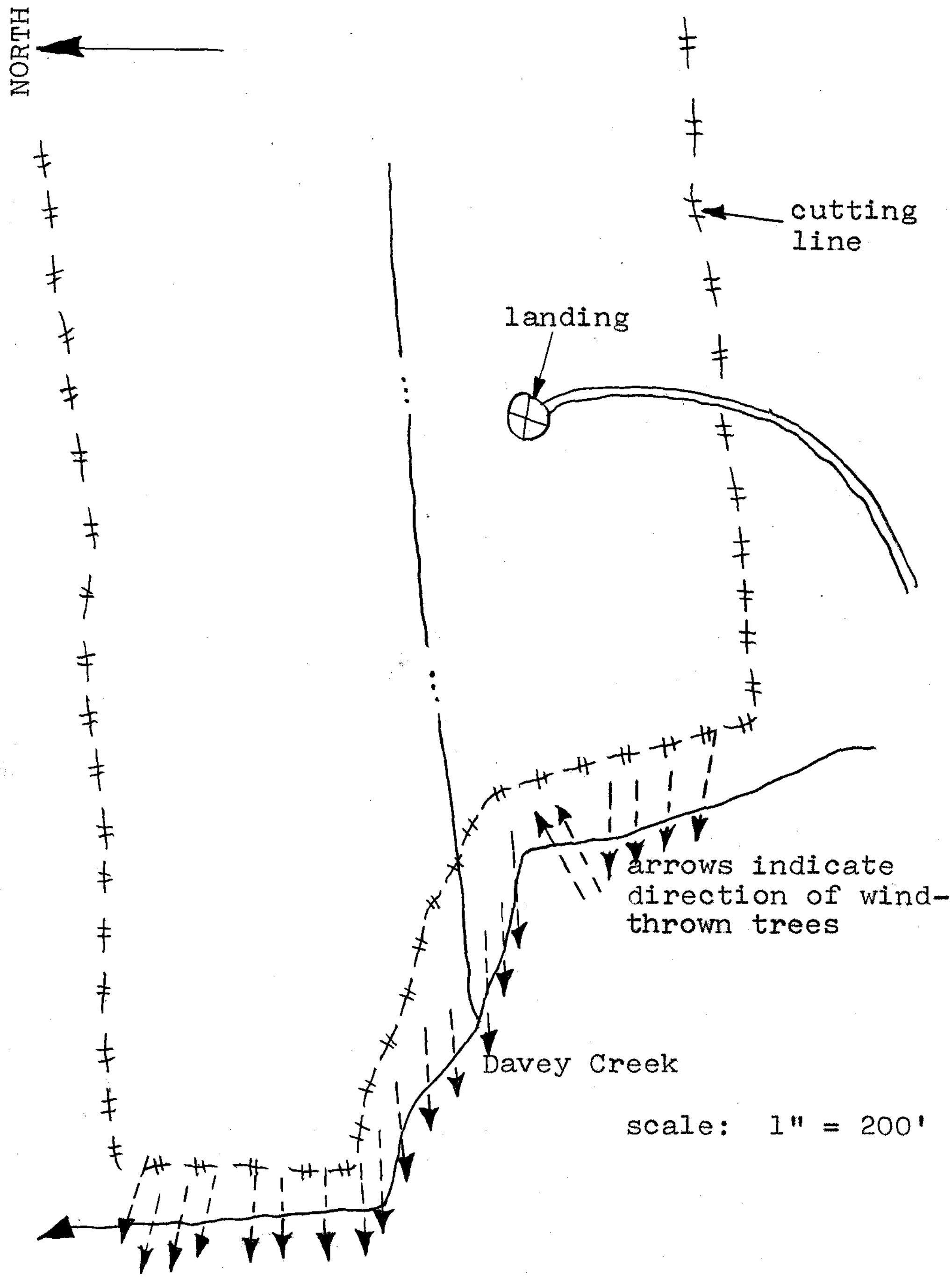


Figure 33. Expanded Davey Creek plan view.

Figure 33. This is because as the wind moves down the unit, it is constricted in the corner. The next winter, winds from the east blew down trees throughout the buffer strip. Many trees at the sides of the clearcut unit were windthrown also. The arrows in Figure 33 show the approximate direction of fall for the windthrown trees, not the actual number of windthrown trees. More than likely the major reason for the high percentage of windthrow in this buffer strip was the long distance to the cutting line in the direction of damaging winds (DISTWIND), and the large proportion of true fir in the stand.

Suppose the cutting line was at point a instead of point b. This is shown in Figure 32. Now the distance to the windward direction is 1360 feet, instead of the original 3140 feet. By using equation a, Table 14, the predicted VOLREM is now 80.7 percent instead of 53 percent. Figure 34 shows the estimation and prediction confidence limits.

Example 4: Bull Run River Buffer Strip (3 winters)

Over a period of three winters, almost 45 percent of the original timber volume was windthrown. The present clearcut is actually two separate clearcuts. Unit 2 was logged first, followed by a large percentage of windthrow in what was later to be unit 1. The buffer strip was left following the harvest of unit 1 windthrow. Figure 35 is a sketch of the area.

The original timber left in the buffer strip was decadent western hemlock, western red cedar, and a few true fir. Defect in the stand was greater than average. The site is very wet with many springs running through the buffer strip and scattered poorly drained areas in the clearcut.

The distance to the cutting line in the direction of damaging winds is 1900 feet, about twice average, and the slope in the direction of damaging winds is less than average. Given the long distance to the cutting line and the wet site with little topographic protection, the buffer could not survive the high velocity winds coming from the east out of the Columbia Gorge.

DISTWIND	1360.0 feet
DISTRIDG	4860.0 feet
ELEVRIDG	1652.0 feet
WETVOL	242.0
ORIENT	2

VOLREM (new)= 80.7 percent

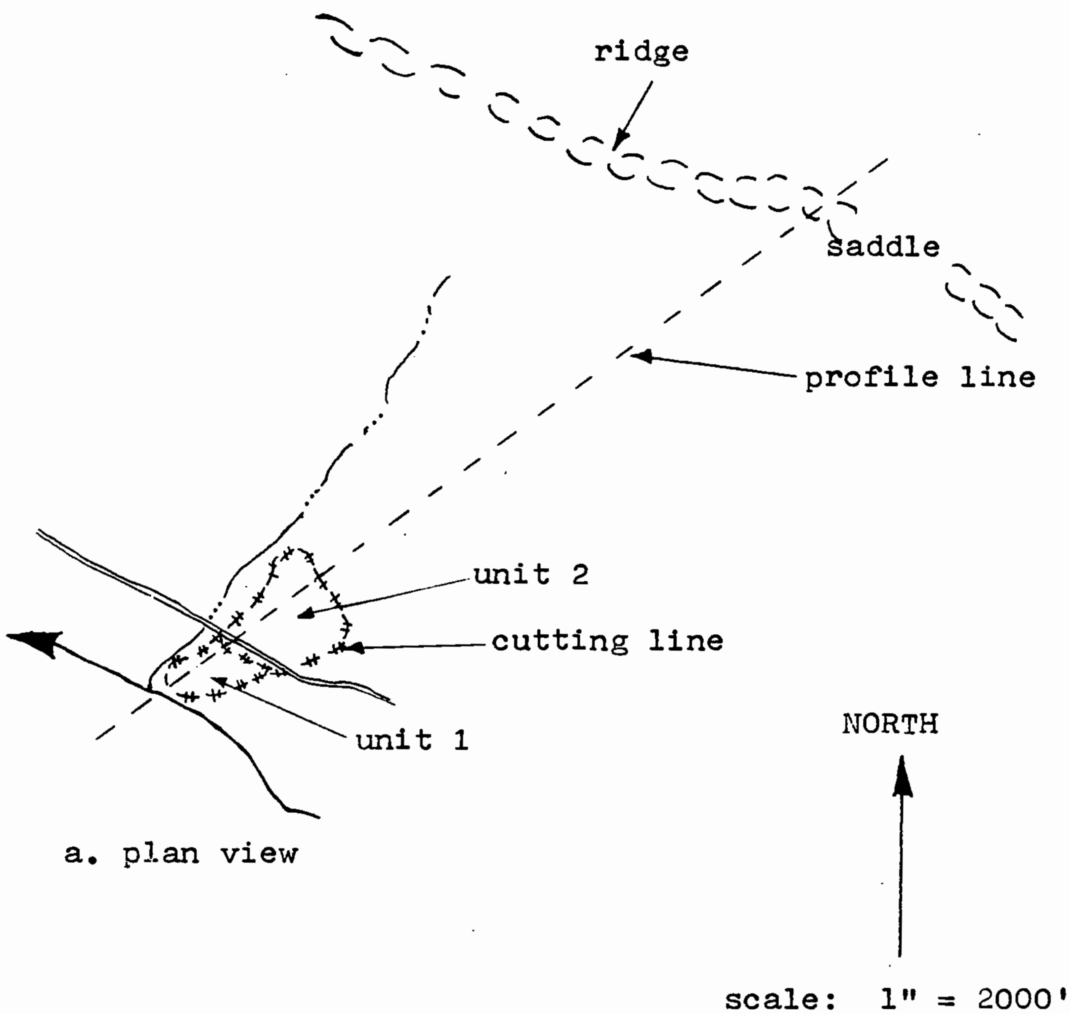
<u>Estimation limits</u>

95% (74.7 percent, 86.7 percent)
99% (72.4 percent, 89.0 percent)

<u>Prediction limits</u>

95% (62.3 percent, 99.1 percent)
99% (55.1 percent,106.2 percent)

Figure 34. Davey Creek prediction example.



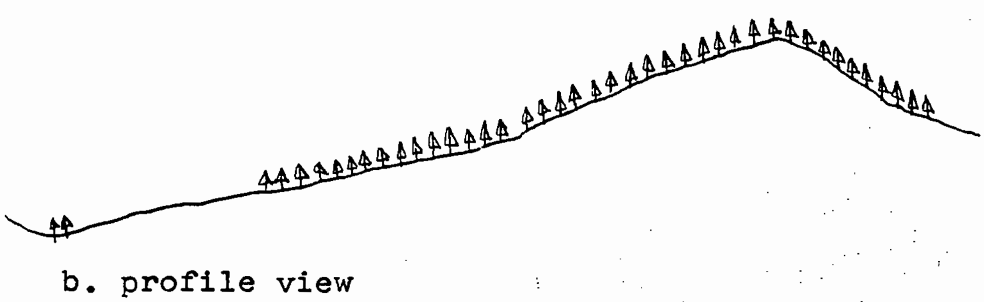


Figure 35. Plan and profile view of Bull Run River buffer strip.

CONCLUSIONS

Stream buffer strips can be useful for stream protection. When properly designed, they can effectively shade the stream after logging and they also serve well as debris barriers for keeping organic material out of the stream channel during logging. Before a buffer strip is established, it is important to define the resources to be protected. Stream buffer strips which neither block debris or shade the stream, especially in unstable conditions, only increase the chance of stream damage due to buffer strip failure.

Buffer Strip Survival

Buffer strip survival, in this study, ranged from 22 to 100 percent of the initial gross timber volume. Damage from wind accounted for about 94 percent of buffer strip mortality, with the remainder due to logging damage, insects or disease. Losses due to wind are often sudden, while losses due to logging or insects and disease become apparent after a longer period of time.

Additional buffer strip timber losses can be expected to take place with time. Wind damage resulted in the loss of from 5 to 13 percent of the initial buffer strip timber volume over the winter of 1975-1976. Wind damage in several buffer strips was catastrophic, while in other buffer strips there were only one or two trees windthrown. Fifty-six percent of the buffer strips in this study suffered no losses over the winter of 1975-1976.

Stream buffer strips had poorer survival if they possessed the following characteristics: larger timber volume per acre, large volumes per tree, increasing numbers of trees per acre taller than 160 feet, and having little protection by standing timber and sheltering major ridges in the direction of damaging winds.

Buffer strips with water tables rising into a tree's rooting zone may also have poorer survival. This was suggested by water table measurements in two buffer strips with windthrow, when water rose into the rooting zone of several nearby windthrown trees.

Larger trees, with heights and diameters above average, were windthrown at a statistically greater rate than trees smaller than average. However, in susceptible buffer strips there was no difference in the windthrow rates of smaller and larger than average Douglas-fir or true fir.

Buffer Strip Effectiveness

Designed buffer strips can be effective for stream temperature control. On the average, a stream buffer strip 85 feet wide shades a stream as well as an average undisturbed canopy, while 75 percent of the undisturbed canopy shading can be achieved with a buffer strip 52 feet wide. Brazier and Brown (1973) found that 90 percent of maximum stream shading could be achieved within a buffer strip width of 55 feet. A non-linear regression between buffer strip width (WIDTH) and ACD accounts for only 45 percent of the variation in the sample. The remaining variation must be explained by other factors such as timber stand basal area per acre (ORIGBA), understory species composition, slope into the creek (SLPCRK), clearcut slope (SLPCC), and other forms of topographic protection. These variables were significant in a multiple linear regression which explained 56 percent of the variation in the sample.

Since many different factors affect stream shading, it is best to identify which trees are shading the stream by using an angular canopy densiometer or an abney. By this means, the trees not shading the stream can be removed.

Finally, the ACD in an uncut stand is usually less than 100 percent. Topography, overstory species types, understory species types, and timber stand density vary in undisturbed stands, resulting in different amounts of shading at each stream.

Buffer Strip Design for Survival

Thorough site reconnaissance is necessary to secure the information necessary to design a stream buffer strip. Ideally, information about local topography, timber, and site should be gathered.

Old windfalls and pits and mounds can be used to identify potential windthrow problems and also the approximate direction of damaging prevailing winds. Understory species may be an aid in identifying wet sites. A walk through the future buffer strip is necessary to identify the two factors described above.

Topographic maps may give important clues about the topography surrounding a future buffer strip. It is helpful to plot the future timber harvest unit on a topographic map to make the following measurements: distance to the cutting line (DISTWIND) and nearest major ridge (DISTRIDG) in the direction of damaging winds. The change in elevation from the buffer strip to the top of the nearest major ridge in the direction of damaging winds can also be easily taken from these maps (ELEVRIDG).

The on-site reconnaissance also gives an opportunity to inspect the overstory timber at the future buffer strip site. Tall, jackstrawed trees may indicate poor natural stability. Many trees with butt or stem rots may suggest a potential for windsnap, if the buffer strip is exposed. Observing stand density is also important. Trees in a dense stand shelter each other from damaging winds, and may not be as windfirm as trees growing in an open stand. Overstory species composition should also be observed, because some tree species tolerate wet sites better than others, thus having a better root system. Windswept trees have inherent windfirmness. Shorter, stocky trees have a lower form point, giving them better stability.

With the ground and map data in hand, multiple linear regression equations can be used to aid a land manager's professional judgement regarding buffer strip design. The equations can be helpful for predicting the percent volume expected to remain (VOLREM) in a stream buffer strip after exposure to damaging winds. Stream buffer strips used to derive the equations are located in the Western Cascades of Oregon, range from 30 to 186 feet in width, and have been exposed from 1 to 15 winters. Of course, the equations are valid only for conditions similar to those in this study.

The land manager must decide whether the predicted loss is acceptable. The standards for an acceptable buffer strip must be defined for each site, by professionals in various fields.

The distance to the cutting line (DISTWIND) in the direction of damaging winds is a factor which can be readily manipulated in the equation. Removing the most susceptible trees must also be considered.

Shortening the distance to the cutting line in the direction of damaging winds may improve survival. However, it is best to substitute various DISTWINDS in the equation to arrive at the best compromise between harvesting efficiency and buffer strip survival. Choosing smaller trees, or trees with a windswept appearance may also improve survival. If the future stream buffer strip is highly susceptible to wind damage, perhaps directional or cable-assist falling may be a more acceptable stream protection tool to avoid potential stream damage, and also a difficult salvage problem.

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APPENDICES

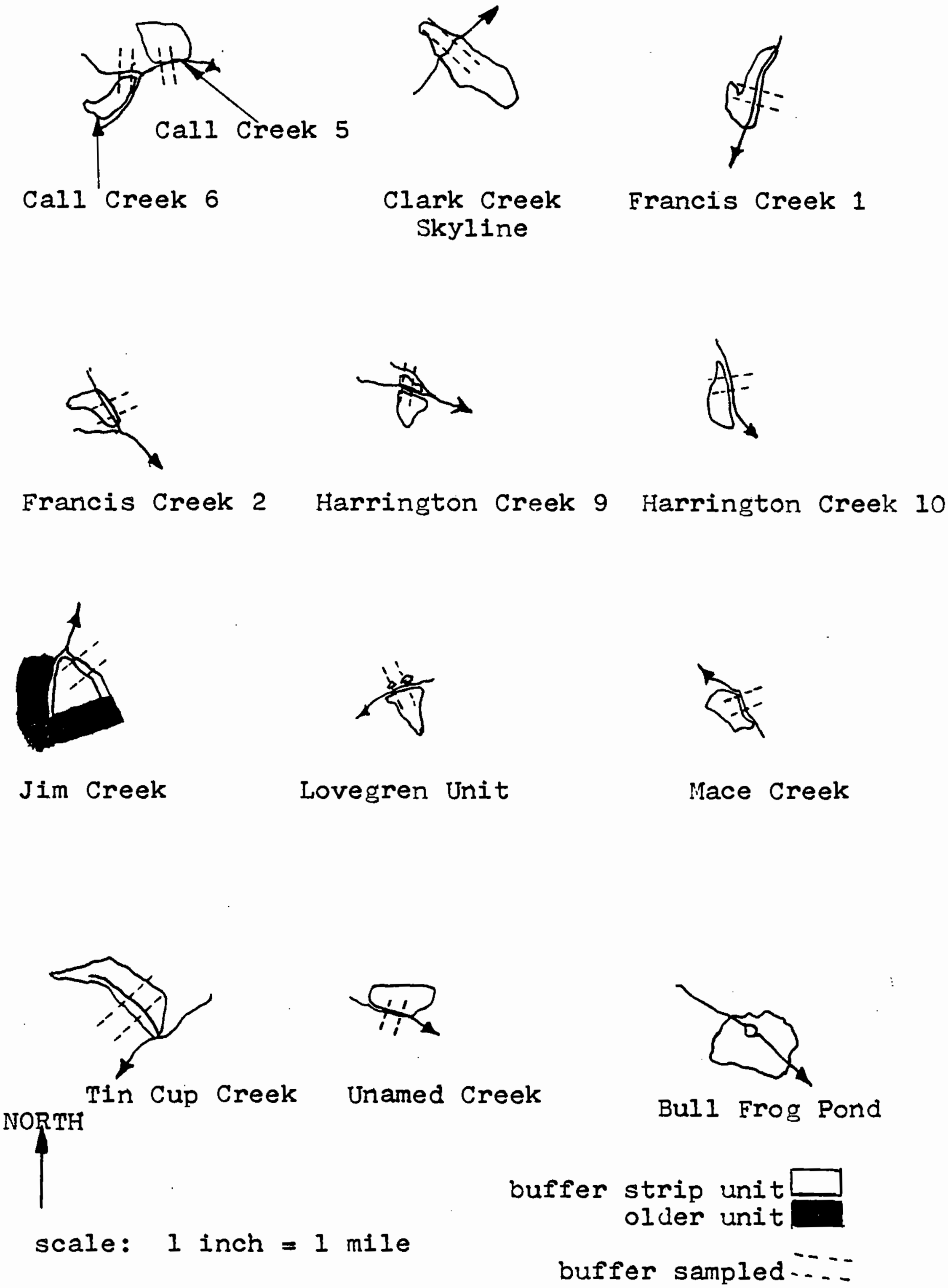
APPENDIX 1

COMMON PLANTS FOUND AT EACH BUFFER STRIP

	Willamette National Forest																			Mt. Hood National Forest						North Umpqua Forest											
	Black Creek	Cadenza Creek	Canal Creek	Cook Creek	Davey Creek	Deer Creek	Elk Creek	Hardy Creek 1	Hardy Creek 2	Lost Creek	Owl Creek	Rider Creek	Perdue Creek	Tidbits Creek	Two-Girls Creek	Winberry Creek	Wolf Creek 1	Wolf Creek 2	Wolf Creek 3	Bedrock Creek	Blister Creek	Bull Run River	N. Fork Bull Run R.	S. Fork Clackamas R.	Whetstone Creek	Call Creek 5	Call Creek 6	Clark Creek	Francis Creek 1	Francis Creek 2	Harrington Creek 9	Harrington Creek 10	Jim Creek	Lovegreen Creek	Mace Creek	Tin Cup Creek	Unamed Creek
azalea (Rhododendron occidentale)						●							●																								
blackberry (Rubus spp.)		●	●			●						●				●	●					●														●	
bracken fern (Pteridium aquilinum)		●	●	●							●			●												●	●				●						
hazel (Corylus spp.)			●				●																					●									
cascara buckthorn (Rhamnus purshiana)																																		●			
coltsfoot (Maianthemum dilatum)																													●	●	●	●		●			
currant (Ribes spp.)																						●				●	●				●	●			●	●	
devils club (Oplopanax horridum)			●					●			●				●				●	●		●	●	●	●												
dogwood (Cornus spp.)										●							●									●		●	●	●			●				
ferns						●	●													●									●	●						●	
grasses		●										●										●			●						●					●	
huckleberry (Vaccinium spp.)																												●					●			●	
lady fern (Athyrium filix-femina)			●																				●	●				●			●			●	●		
lilly																										●											
mountain maple (Acer glabrum)											●			●																							
Oregon grape (Berberis nervosa)	●			●	●	●	●	●		●	●	●		●		●	●		●		●		●		●		●	●					●	●		●	●
oxalis (Oxalis oregana)	●		●			●		●			●	●		●	●	●						●	●	●				●					●		●	●	●
pacific yew (Taxus brevifolia)	●		●	●		●	●					●	●			●	●	●	●		●												●				
red alder (Alnus rubra)		●	●			●	●	●	●	●		●										●			●			●						●			
red huckleberry (Vaccinium parvifolium)	●	●	●	●		●		●		●			●	●	●	●	●		●		●	●	●														
rhododendron (Rhododendron spp.)	●	●		●		●		●						●					●						●											●	
salal (Gaultheria shalon)										●		●				●													●	●			●	●			
salmonberry (Rubus spectabilis)		●		●				●	●													●	●		●		●										
sedges (Carex spp.)						●																															
skunk cabbage (Lysichitum americanum)								●														●		●													
sticky currant (Ribes viscosissimum)			●																	●								●					●				
sword fern (Polystichum munitum)	●		●	●				●	●		●	●		●	●	●	●	●	●		●			●		●	●	●			●	●	●	●	●		●
thimbleberry (Rubus parviflorus)																					●																
thinleaf huckleberry (Vaccinium membranaceum)					●	●		●			●		●			●				●		●	●	●	●												
trillium (Trillium ovatum)	●			●											●		●	●															●	●			
vanilla leaf (Achlys triphylla)				●				●																										●			
vine maple (Acer circinatum)	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●		●	●	●			●	●		●	●	●	●	●	●	●	●	●
wild rose (Rosa spp.)																							●		●												

APPENDIX 2

HARVESTING UNIT GEOMETRY



APPENDIX 2 (cont.)

Black Creek

Blowout Creek

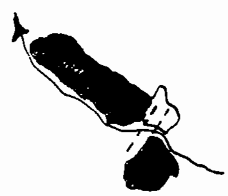
Cadenza Creek

Canal Creek

Cook Creek

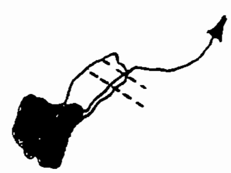
Davey Creek

Deer Creek



Elk Creek

Hardy Creek 1



Hardy Creek 2

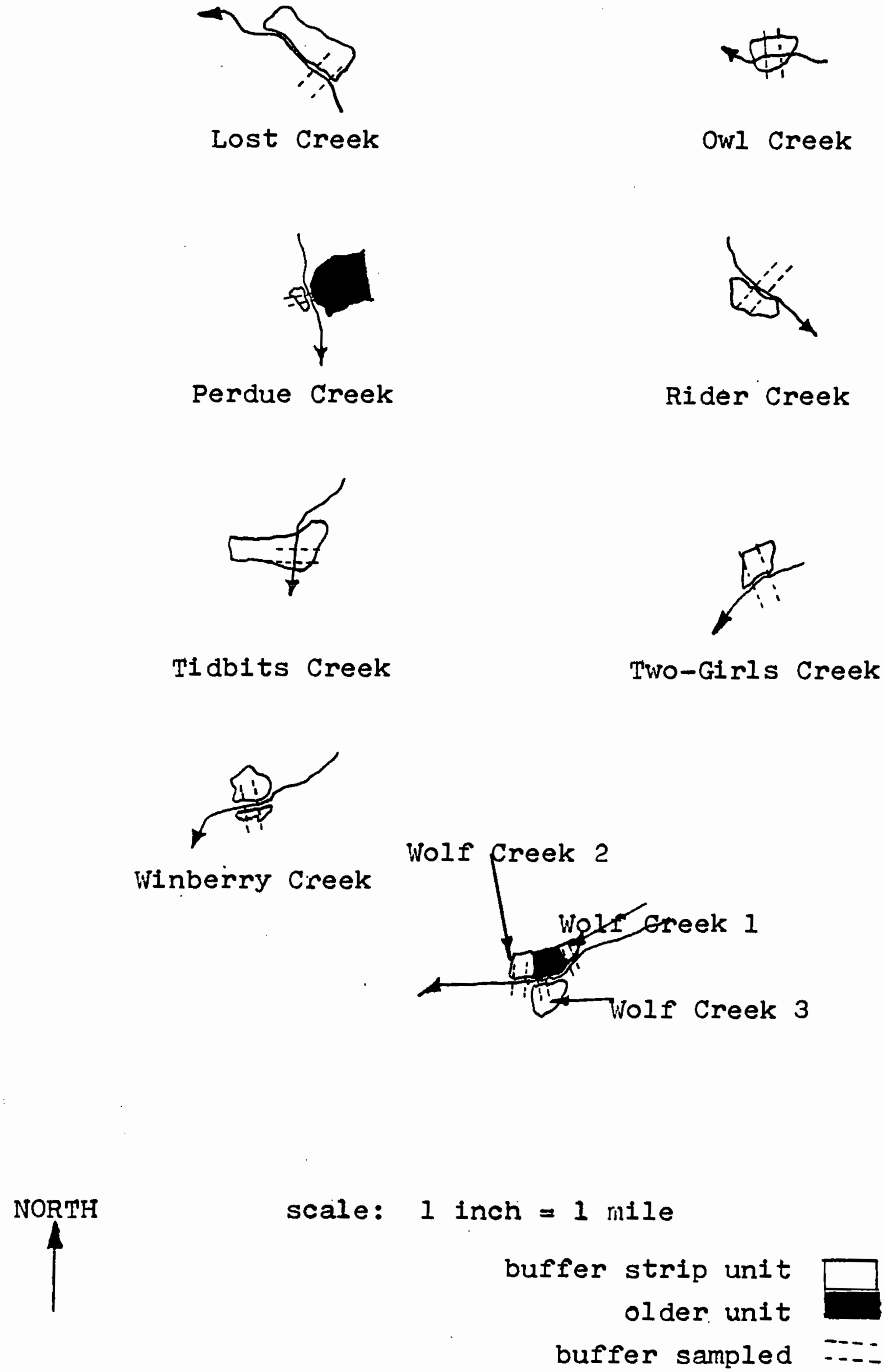
NORTH

buffer strip unit
older unit

scale: 1 inch = 1 mile

buffer sampled

APPENDIX 2 (cont.)

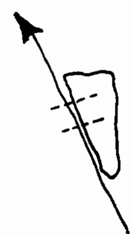


APPENDIX 2 (cont.)

Bedrock Creek

Blister Creek

North Fork Bull Run River



South Fork Clackamas River

Bull Run River

Whetstone Creek

NORTH scale: 1 inch = 1 mile

buffer strip unit

older unit

buffer sampled

APPENDIX 3

BUFFER STRIP VALUES AND LOSSES
(Values in thousands of dollars based on total volumes)

Unit: Willamette Forest

	Originally					September, 1976					
Buffer Name	DF	WH	WRC	TF	TOTAL	DF	WH	WRC	TF	TOTAL	LOSS
Black Creek	38.7	20.4	7.6	0.9	67.6	38.7	19.0	7.0	0.0	64.7	2.9
Blowout Creek	11.0	9.1	10.9	0.0	31.0	11.0	8.3	10.8	0.0	30.1	0.9
Cadenza Creek	1.6	2.0	0.0	0.0	3.6	1.6	1.9	0.0	0.0	3.5	0.1
Canal Creek	25.4	5.1	0.1	0.0	30.6	19.2	4.4	0.1	0.0	23.7	6.9
Cook Creek	34.9	2.2	2.9	0.0	40.0	34.5	2.0	2.5	0.0	39.0	1.0
Davey Creek	19.8	6.0	0.0	9.4	35.2	19.5	0.8	0.0	1.5	21.8	13.4
Deer Creek	27.6	9.6	0.9	0.0	38.1	25.2	8.9	0.7	0.0	34.8	3.3
Elk Creek	66.6	2.4	1.0	0.3	70.3	27.6	0.7	0.7	0.3	29.3	41.0
Hardy Creek, 1	52.7	7.7	6.0	0.0	66.4	46.6	7.1	5.4	0.0	59.1	7.3
Hardy Creek, 2	26.6	3.8	1.0	0.0	31.4	23.4	2.7	0.6	0.0	26.7	4.7
page total	304.9	68.3	30.4	10.6	414.2	247.3	55.8	27.8	1.8	332.7	81.5

APPENDIX 3 (cont.)

Unit: Willamette Forest

	Originally					September, 1976					
Buffer Name	DF	WH	WRC	TF	TOTAL	DF	WH	WRC	TF	TOTAL	LOSS
Lost Creek	16.2	1.4	0.5	0.0	18.1	15.0	1.3	0.5	0.0	16.8	1.3
Owl Creek	58.0	4.2	0.4	0.0	62.6	34.0	1.0	0.0	0.0	35.0	27.6
Perdue Creek	26.3	3.4	3.5	0.0	33.2	26.3	2.5	1.4	0.0	30.2	3.0
Rider Creek	11.6	3.8	1.0	0.0	16.4	7.3	1.7	0.7	0.0	9.7	6.7
Tidbits Creek	19.7	3.3	0.0	0.0	23.0	15.5	2.9	0.0	0.0	18.4	4.6
Two-Girls Creek	11.6	11.1	0.6	0.0	23.3	10.5	8.3	0.0	0.0	18.8	4.5
Winberry Creek	19.7	3.4	0.2	0.0	23.3	12.0	2.5	0.2	0.0	14.7	8.6
Wolf Creek, 1	3.6	1.1	10.7	0.0	15.4	3.7	0.8	8.1	0.0	12.6	2.8
Wolf Creek, 2	0.4	0.4	0.6	0.0	1.4	0.4	0.3	0.6	0.0	1.3	0.1
Wolf Creek, 3	63.8	12.2	2.2	0.0	78.2	32.4	5.4	1.5	0.0	39.3	38.9
page total	230.9	44.3	19.7	0.0	294.9	157.1	26.7	13.0	0.0	196.8	98.1
grand total (Willamette Forest)	535.8	112.6	50.1	10.6	709.1	404.4	82.5	40.8	1.8	529.5	179.6

APPENDIX 3 (cont.)

Unit: Mt. Hood Forest

Buffer Name	Originally DF	WH	WRC	TF	TOTAL	September, 1976 DF	WH	WRC	TF	TOTAL	LOSS
Bear Creek	2.7	6.9	4.0	0.0	13.6	0.0	2.0	0.9	0.0	2.9	10.7
Bedrock Creek	9.5	17.9	5.0	2.5	34.9	9.5	15.4	4.0	0.7	28.9	6.0
Blister Creek	43.0	2.7	0.0	0.0	45.7	43.0	2.6	0.0	0.0	45.6	0.1
North Fork Bull Run River	2.9	4.9	1.1	0.0	8.9	2.9	4.9	1.1	0.0	8.9	0.0
South Fork Clackamas River	79.5	22.7	8.1	12.5	122.8	20.8	4.1	2.1	2.1	29.1	93.7
Bull Run River	0.0	6.5	12.0	2.8	21.3	0.0	2.8	6.8	1.7	11.3	10.0
Whetstone Creek	8.5	0.4	1.5	0.0	10.4	8.5	0.4	1.5	0.0	10.4	0.0
grand total (Mt. Hood Forest)	146.1	62.0	31.7	17.8	257.6	84.7	32.2	16.4	4.5	137.1	120.5

APPENDIX 3 (cont.)

Unit: North Umpqua Forest

Buffer Name	Originally DF	WH	WRC	TF	TOTAL	September, 1976 DF	WH	WRC	TF	TOTAL	LOSS
Call Creek, 5	6.6	0.6	0.2	0.0	7.4	6.6	0.6	0.2	0.0	7.4	0.0
Call Creek, 6	0.7	0.6	0.3	0.0	1.6	0.7	0.3	0.1	0.0	1.1	0.5
Clark Creek	0.0	3.4	1.2	0.0	4.6	0.0	2.2	0.9	0.0	3.1	1.5
Francis Creek, 1	3.2	10.5	0.3	0.0	14.0	1.2	10.5	0.3	0.0	12.0	2.0
Francis Creek, 2	1.2	1.2	3.0	0.0	5.4	0.7	0.9	2.7	0.0	4.3	1.1
Harrington Creek, 9	6.7	2.8	2.4	0.0	11.9	5.5	2.6	2.0	0.0	10.1	1.8
Harrington Creek, 10	2.0	0.8	0.2	0.0	3.0	2.0	0.8	0.2	0.0	3.0	0.0
Jim Creek	10.1	1.1	5.7	0.0	16.9	3.4	0.5	5.2	0.0	9.1	7.8
Lovegren	0.0	2.8	0.8	0.0	3.6	0.0	2.3	0.8	0.0	3.1	0.5
Mace Creek	0.0	2.4	0.0	0.0	2.4	0.0	2.2	0.0	0.0	2.2	0.2
Tin Cup Creek	20.9	12.7	0.5	0.0	34.1	13.8	11.0	0.5	0.0	25.3	8.8
Unamed Creek	0.3	0.0	0.2	0.0	0.5	0.3	0.0	0.1	0.0	0.4	0.1
grand total (North Umpqua Forest)	51.7	38.9	14.8	0.0	105.4	34.2	33.9	13.0	0.0	81.1	24.3

APPENDIX 4

BUFFER STRIP VARIABLES

Variable Unit Summary

Variable	(Column)	Units
ELEV	(2)	feet
Est. acr.	(3)	acres
WIDTH	(4)	feet
Est. length	(5)	feet
Sample length	(6)	feet
SLPCRK	(7)	percent
SLPCC	(8)	percent
SOILDPT	(9)	feet
STABRATE	(11)	no units
UNSPECIE	(12)	no units
Dir. wind	(13)	NW, NE, SE, SW
DISTWIND	(14)	feet
SLPWIND	(15)	percent
DISTRIDG	(16)	feet
ELEVRIDG	(17)	feet
VERTHOR	(18)	percent
ORIENT	(19)	no units
EXPCODE	(20)	no units
NOSIDES	(21)	no units
OVSPECIE	(22)	no units
NETGROSS	(23)	percent
ORIGVOL	(24)	MBF/acre (gross)
ORIGBA	(25)	square feet/acre (gross)
VOLTREE	(26)	MBF (gross)
NOSTEMS	(27)	no units
LOGDAM	(28)	trees/acre
TOTVOL (total volume)	(33)	MBF (gross)
VOLREM	(34)	percent

APPENDIX 4 (cont.)

Variable	(Column)	Units
VOLREM*	(35)	percent
Vol. down	(36)	percent
Vol. dead	(37)	percent
Vol. dyn. (dying)	(38)	percent
ACD	(39)	percent
Buff. shade	(40)	yes = buffer strip shade no = uncut stand shade
AVHTALL	(41)	feet
AVHTTALL	(42)	feet
NOTALL	(43)	~~no units~~ trees/acre
NOSMALL	(44)	~~no units~~ trees/acre
No. of winters	(45)	years

APPENDIX 4 (cont.)

Unit: Willamette Forest

Buffer Name	(1) Legal desc.	(2) ELEV	(3) Est. acr.	(4) WIDTH	(5) Est. length
Black Creek	S. 22,T21S,R5E	2900	5.0	144	1500
Blowout Creek	S. 35,T10S,R5E	1600	2.2	115	760
Cadenza Creek	S. 29,T14S,R6E	3400	0.6	50	500
Canal Creek	S. 11,T11S,R4E	1990	2.4	73	800
Cook Creek	S. 17,T15S,R5E	1840	2.9	140	900
Davey Creek	S. 29,T25S,R4E	4000	2.0	70	1250
Deer Creek	S. 4,T15S,R4E	2550	2.5	165	700
Elk Creek	S. 16,T19S,R6E	3100	2.9	186	720
Hardy Creek 1	S. 9,T18S,R5E	2800	3.8	155	1050
Hardy Creek 2	S. 20,T18S,R5E	3800	1.6	58	600
Lost Creek	S. 13,T16S,R6E	1780	2.0	65	1300
Owl Creek	S. 8,T15S,R4E	3000	1.9	40	1200
Perdue Creek	S. 18,T19S,R4E	2700	1.0	110	470
Rider Creek	S. 19,T17S,R5E	2960	1.3	70	800
Tidbits Creek	S. 22,T15S,R4E	2600	1.7	58	700
Two-Girls Creek	S. 14,T14S,R4E	2450	2.4	80	1000
Winberry Creek	S. 22,T15S,R4E	2160	2.0	55	760
Wolf Creek 1	S. 1,T15S,R5E	3000	3.5	135	1100
Wolf Creek 2	S. 1,T15S,R5E	3200	0.4	30	600
Wolf Creek 3	S. 1,T15S,R5E	3050	3.6	70	1100

APPENDIX 4 (cont.)

Unit: Willamette Forest

Buffer Name	(6) Sample length	(7) SLPCRK	(8) SLPCC	(9) SOIL DPT.
Black Creek	500	70	20	11.0
Blowout Creek	400	68	61	3.5
Cadenza Creek	400	32	30	9.0
Canal Creek	500	73	63	2.0
Cook Creek	500	67	80	4.5
Davey Creek	600	46	33	8.0
Deer Creek	400	85	40	7.5
Elk Creek	400	65	30	10.0
Hardy Creek 1	500	22	25	8.5
Hardy Creek 2	500	38	25	8.5
Lost Creek	500	17	13	12.0
Owl Creek	500	67	70	6.0
Perdue Creek	400	56	56	4.0
Rider Creek	700	47	32	6.0
Tidbits Creek	500	80	84	3.0
Two-Girls Creek	500	47	70	3.0
Winberry Creek	500	51	25	6.0
Wolf Creek 1	400	50	41	4.0
Wolf Creek 2	500	79	66	5.0
Wolf Creek 3	400	57	43	6.0

APPENDIX 4 (cont.)

Unit: Willamette Forest

Buffer Name	(10) Soil type	(11) STABRATE
Black Creek	gravelly cobbly loam	1
Blowout Creek	gravelly sandy loam	2
Cadenza Creek	gravelly loam	1
Canal Creek	gravelly loam	2
Cook Creek	gravelly loam	1
Davey Creek	gravelly loam	3
Deer Creek	gravelly cobbly loam	3
Elk Creek	gravelly sandy loam	1
Hardy Creek 1	gravelly sandy loam	1
Hardy Creek 2	gravelly sandy loam	3
Lost Creek	gravelly cobbly sandy loam	2
Owl Creek	gravelly cobbly loam	1
Perdue Creek	gravelly loam	1
Rider Creek	gravelly sandy loam	2
Tidbits Creek	gravelly loam	2
Two-Girls Creek	gravelly loam	1
Winberry Creek	gravelly sandy clay loam	3
Wolf Creek 1	gravelly loam	1
Wolf Creek 2	gravelly loam	1
Wolf Creek 3	gravelly loam	2

APPENDIX 4 (cont.)

Unit: Willamette Forest

Buffer Name	(12) UNSPECIE	(13) Dir. wind	(14) DIST WIND	(15) SLP WIND	(16) DIST RIDG
Black Creek	3.0	SW	735	21	4900
Blowout Creek	3.0	SW	590	89	4900
Cadenza Creek	2.0	—	0	20	6600
Canal Creek	4.0	SW	790	43	1214
Cook Creek	2.0	SW	610	80	1300
Davey Creek	2.0	E	3140	33	4860
Deer Creek	4.0	E	770	30	2640
Elk Creek	2.0	SW	3000	5	6000
Hardy Creek 1	4.0	SW	1478	14	9700
Hardy Creek 2	4.0	SW	1429	29	2376
Lost Creek	2.0	E	990	21	3660
Owl Creek	4.0	E	633	16	6230
Perdue Creek	3.0	SW	530	50	1848
Rider Creek	3.0	SW	3000	11	5491
Tidbits Creek	2.0	E	750	100	1900
Two-Girls Creek	3.5	—	0	7	3200
Winberry Creek	3.0	E	400	20	15048
Wolf Creek 1	2.5	—	0	20	5350
Wolf Creek 2	2.5	—	0	20	4800
Wolf Creek 3	3.5	E	920	24	5200

APPENDIX 4 (cont.)

Unit: Willamette Forest

Buffer Name	(17) ELEV. RIDGE	(18) VERT. HOR.	(19) ORIENT	(20) EXP. CODE	(21) NO. SIDES
Black Creek	2499	51	NW,1	2	1
Blowout Creek	2352	48	NW,1	2	2
Cadenza Creek	1782	27	NW,1	1	1
Canal Creek	813	67	NW,1	2	2
Cook Creek	975	75	SE,2	2	2
Davey Creek	1652	34	NW,1	3	1
Deer Creek	1135	43	SE,2	3	1
Elk Creek	960	16	SW,1	2	2
Hardy Creek 1	2425	25	NE,2	2	1
Hardy Creek 2	1045	44	NE,2	4	2
Lost Creek	1684	46	NW,1	3	1
Owl Creek	1558	25	NW,1	4	2
Perdue Creek	407	22	SE,2	2	1
Rider Creek	275	5	SE,2	2	1
Tidbits Creek	1159	61	SW,1	4	2
Two-Girls Creek	192	6	SW,1	1	1
Winberry Creek	1806	12	SW,1	3	2
Wolf Creek 1	696	13	SW,1	1	1
Wolf Creek 2	624	13	SW,1	1	1
Wolf Creek 3	676	13	SW,1	4	2

APPENDIX 4 (cont.)

Unit: Willamette Forest

Buffer Name	(22) OVSPECIE	(23) NET GROSS	(24) ORIG. VOL.	(25) ORIG. BA.	(26) VOL. TREE	(27) NO. STEMS
Black Creek	6	64	125	409	1.27	98
Blowout Creek	6	68	132	482	1.71	77
Cadenza Creek	6	71	56	187	1.26	44
Canal Creek	2	63	104	311	2.54	41
Cook Creek	2	85	82	262	1.23	67
Davey Creek	5	85	121	386	1.54	79
Deer Creek	4	75	108	326	1.94	56
Elk Creek	2	.73	162	452	2.86	56
Hardy Creek 1	4	79	118	362	2.00	59
Hardy Creek 2	2	79	132	368	3.41	39
Lost Creek	2	78	129	378	3.34	39
Owl Creek	2	78	206	526	2.06	100
Perdue Creek	4	78	221	605	3.13	71
Rider Creek	4	76	94	269	1.88	50
Tidbits Creek	2	85	80	215	3.54	23
Two-Girls Creek	6	75	80	272	3.17	25
Winberry Creek	2	72	82	246	2.89	28
Wolf Creek 1	8	73	41	144	0.62	66
Wolf Creek 2	8	69	35	177	0.61	57
Wolf Creek 3	4	80	145	429	2.60	56

APPENDIX 4 (cont.)

Unit: Willamette Forest

Buffer Name	(28) LOGDAM	(29) %DF	(30) %WH	(31) %TF	(32) %WRC	(33) TOT. VOL.	(34) VOL. REM.
Black Creek	3	43	40	2	15	634M	100.0
Blowout Creek	5	29	35	0	36	295M	96.5
Cadenza Creek	3	32	68	0	0	31M	97.0
Canal Creek	11	85	14	0	1	253M	89.0
Cook Creek	11	80	9	0	11	241M	100.0
Davey Creek	1	46	21	33	0	248M	53.0
Deer Creek	9	59	38	0	3	285M	95.0
Elk Creek	2	90	6	1	3	474M	47.4
Hardy Creek 1	2	68	18	0	14	447M	91.4
Hardy Creek 2	3	76	19	0	5	204M	86.0
Lost Creek	4	83	12	0	5	116M	98.0
Owl Creek	8	90	9	0	1	393M	58.7
Perdue Creek	3	73	16	0	11	256M	100.0
Rider Creek	0	57	34	0	9	120M	57.0
Tidbits Creek	17	78	22	0	0	139M	91.0
Two-Girls Creek	4	42	55	3	0	193M	91.0
Winberry Creek	1	78	15	0	7	166M	64.0
Wolf Creek 1	4	15	78	0	7	144M	94.2
Wolf Creek 2	5	17	31	4	48	14M	86.0
Wolf Creek 3	2	72	24	0	4	517M	50.3

APPENDIX 4 (cont.)

Unit: Willamette Forest

Buffer Name	(35) VOL.* REM.	(36) Vol. down	(37) Vol. dead	(38) Vol. dyn.	(39) ACD	(40) Buff. shade
Black Creek	94.0	0.0	6.0	0.0	87	yes
Blowout Creek	96.5	3.5	0.0	0.0	67	yes
Cadenza Creek	96.0	3.0	1.0	0.0	29	yes
Canal Creek	87.0	11.0	0.0	2.0	62	yes
Cook Creek	97.0	0.0	0.0	3.0	33	yes
Davey Creek	53.0	47.0	0.0	0.0	83	no
Deer Creek	92.0	5.0	2.0	1.0	26	no
Elk Creek	42.0	52.6	5.1	0.3	—	no
Hardy Creek 1	89.3	8.6	1.1	1.0	70	no
Hardy Creek 2	84.0	14.0	0.0	2.0	58	yes
Lost Creek	94.0	2.0	4.0	0.0	60	no
Owl Creek	57.0	41.3	0.0	1.7	38	yes
Perdue Creek	93.0	0.0	3.0	4.0	71	yes
Rider Creek	57.0	43.0	0.0	0.0	52	yes
Tidbits Creek	81.0	9.0	0.0	10.0	30	yes
Two-Girls Creek	79.0	9.0	4.0	8.0	75	no
Winberry Creek	64.0	36.0	0.0	0.0	37	yes
Wolf Creek 1	79.0	5.8	2.0	13.2	62	no
Wolf Creek 2	82.0	14.0	3.0	1.0	44	no
Wolf Creek 3	50.1	49.7	0.0	0.2	43	yes

APPENDIX 4 (cont.)

Unit: Willamette Forest

Buffer Name	(41) AVHT ALL	(42) AV HTTALL	(43) NO. TALL	(44) NO. SMALL	(45) No. of winters
Black Creek	129	147	27	22	7
Blowout Creek	130	148	22	24	3
Cadenza Creek	119	129	9	9	2
Canal Creek	130	158	14	14	2
Cook Creek	107	153	16	33	3
Davey Creek	112	130	6	42	3
Deer Creek	135	146	19	13	15
Elk Creek	137	162	22	18	3
Hardy Creek 1	136	152	19	12	11
Hardy Creek 2	145	166	17	10	3
Lost Creek	141	162	16	8	9
Owl Creek	149	179	48	34	3
Perdue Creek	150	165	34	9	4
Rider Creek	140	162	19	11	4
Tidbits Creek	146	166	11	10	3
Two-Girls Creek	144	158	14	4	3
Winberry Creek	126	163	11	11	4
Wolf Creek 1	99	120	3	31	4
Wolf Creek 2	90	114	0	29	4
Wolf Creek 3	135	161	21	17	1

APPENDIX 4 (cont.)

Unit: Mt. Hood Forest

Buffer Name	(1) Legal descript.	(2) ELEV.	(3) Est. acr.	(4) WIDTH	(5) Est. length	(6) Sample length	(7) SLPCRK	(8) SLPCC	(9) SOIL DPT.
Bear Creek	S. 9,T1S,R6E	1700	2.4	92	1100	500	80	25	——
Bedrock Creek	S. 30,T1S,R8E	2880	2.3	105	1160	500	36	28	3.4
Blister Creek	S. 14,T7S,R5E	2160	2.5	59	1200	500	74	60	2.5
Bull Run River	S. 13,T1S,R7E	2400	1.7	115	600	500	80	22	2.5
N. Fork Bull Run	S. 11,T1S,R6E	1600	2.0	85	1100	500	62	20	4.0
S. Fork Clackamas	S. 25,T5S,R4E	3600	3.6	69	2400	500	43	56	6.5
Whetstone Creek	S. 10,T8S,R5E	3600	0.8	45	700	500	78	51	3.5

APPENDIX 4 (cont.)

Unit: Mt. Hood Forest

Buffer Name	(10) Soil type	(11) STABRATE	(12) UNSPECIE	(13) Dir. wind	(14) DIST WIND	(15) SLP WIND	(16) DIST RIDGE	(17) ELEV. RIDGE
Bear Creek	—	—	—	—	—	—	—	—
Bedrock Creek	stony gravelly loam	1	3.0	E	1600	33	4560	820
Blister Creek	gravelly loam	2	2.0	E	528	48	700	273
Bull Run River	stony loam	2	4.0	E	1900	23	7600	2204
N. Fork Bull Run	silt loam	1	4.0	—	0	13	10000	1300
S. Fork Clackamas	gravelly sandy loam	2	4.0	E	1200	64	3763	715
Whetstone Creek	gravelly clay loam	2	3.0	SW	300	36	2930	469

APPENDIX 4 (cont.)

Unit: Mt. Hood Forest

Buffer Name	(18) VERT HOR.	(19) ORIENT	(20) EXP CODE	(21) NO. SIDES	(22) OVSPECIE	(23) NET GROSS	(24) ORIG. VOL.	(25) ORIG BA	(26) VOL. TREE
Bear Creek	—	SW,1	—	1	7	—	67	—	1.3
Bedrock Creek	18	NW,1	3	1	9	56	180	518	3.1
Blister Creek	39	SE,2	3	2	2	87	102	308	1.4
Bull Run River	29	NW,1	3	1	9	58	164	559	2.4
N. Fork Bull Run	13	SW,1	1	1	6	74	39	148	1.1
S. Fork Clackamas	19	NW,1	3	1	7	70	281	809	2.5
Whetstone Creek	75	NE,2	2	1	3	75	90	308	1.1

APPENDIX 4 (cont.)

Unit: Mt. Hood Forest

Buffer Name	(27) NO. STEMS	(28) LOGDAM	(29) %DF	(30) %WH	(31) %TF	(32) %WRC	(33) TOT. VOL.	(34) VOL. REM.	(35) VOL.* REM.	(36) Vol. down	(37) Vol. dead
Bear Creek	49	—	10	55	0	35	154M	88.0	24.0	12.0	58.0
Bedrock Creek	58	5	15	59	7	19	412M	87.0	83.0	13.0	2.0
Blister Creek	87	15	90	10	0	0	260M	100.0	97.0	0.0	3.0
Bull Run River	69	0	0	29	9	62	273M	55.1	54.3	44.9	0.8
N. Fork Bull Run	36	2	31	55	0	14	79M	100.0	100.0	0.0	0.0
S. Fork Clackamas	112	1	50	26	15	9	670M	23.0	23.0	77.0	0.0
Whetstone Creek	81	6	76	6	18	0	72M	100.0	100.0	0.0	0.0

APPENDIX 4 (cont.)

Unit: Mt. Hood Forest

Buffer Name	(38) Vol. dying	(39) ACD	(40) Buff shade	(41) AVHT ALL	(42) AV HTTALL	(43) NO. SMALL	(44) NO. TALL	(45) Number of winters
Bear Creek	6	71	yes	—	—	—	—	7
Bedrock Creek	2	62	no	145	160	34	5	11
Blister Creek	0	56	yes	127	171	31	34	2
Bull Run River	0	42	no	106	132	3	15	8
N. Fork Bull Run	0	88	yes	150	157	55	8	1
S. Fork Clackamas	0	—	no	136	150	29	10	3
Whetstone Creek	0	80	no	125	133	14	11	5

APPENDIX 4 (cont.)

Unit: North Umpqua Forest

Buffer Name	(1) Legal descript.	(2) ELEV	(3) Est. acr.	(4) WIDTH	(5) Est. length	(6) Sample length	(7) SLP CRK	(8) SLP CC
Call Creek 5	S. 21,T24S,R1W	2750	1.1	50	1100	600	64	64
Call Creek 6	S. 21,T24S,R1W	2900	0.8	50	700	600	56	58
Clark Creek	S. 23,T23S,R1W	1680	1.6	48	825	700	62	58
Francis Creek 1	S. 2,T24S,R1W	2450	4.7	50	2800	600	58	57
Francis Creek 2	S. 12,T24S,R1W	2240	2.2	48	1300	600	60	60
Harrington Creek 9	S. 5,T25S,R2W	2300	3.7	78	1000	600	70	35
Harrington Creek 10	S. 5,T25S,R2W	2100	1.6	55	1400	600	70	33
Jim Creek	S. 17,T27S,R3W	1680	1.7	58	760	400	42	36
Lovegren	S. 1,T23S,R1W	1580	0.9	30	900	700	72	52
Mace Creek	S. 29,T25S,R1W	2400	0.8	50	800	600	78	58
Tin Cup Creek	S. 24,T24S,R1W	2200	3.3	67	1100	600	65	41
Unamed Creek	S. 1,T26S,R3W	1250	0.6	20	1200	600	40	20
Bull Frog Pond	S. 35,T25S,R3W	1690	2.5	60	1600	600	5	20

APPENDIX 4 (cont.)

Unit: North Umpqua Forest

Buffer Name	(9) SOIL DPT	(10) Soil Type	(11) STAB RATE	(12) UNSPECIE	(13) Dir. Wind	(14) DIST WIND	(15) SLP WIND
Call Creek 5	2.7	very gravelly loam	2	2.0	——	0	52
Call Creek 6	2.7	very gravelly loam	2	3.0	SW	1600	34
Clark Creek	5.5	very gravelly silty clay loam	1	3.0	E	2900	58
Francis Creek 1	3.5	very gravelly clay loam	2	2.0	SW	1200	25
Francis Creek 2	3.5	very gravelly loam	2	2.0	SW	463	75
Harrington Creek 9	6.0	very gravelly silty clay loam	1	3.0	SW	960	55
Harrington Creek 10	3.0	clay	2	2.0	SW	1000	12
Jim Creek	6.0	sandy clay loam	3	3.0	SW	3000	18
Lovegren	5.5	very gravelly silty clay loam	2	3.0	SW	600	47
Mace Creek	3.5	very gravelly clay loam	2	3.0	SW	450	51
Tin Cup Creek	4.0	very gravelly silty clay loam	2	2.5	E	680	16
Unamed Creek	4.0	red stony clay	1	2.5	E	800	0
Bull Frog Pond	8.0	——	1	2.5	SW	1000	10

APPENDIX 4 (cont.)

Unit: North Umpqua Forest

Buffer Name	(16) DIST RIDG	(17) ELEV RIDG	(18) VERT HOR	(19) ORIENT	(20) EXP CODE	(21) No. SIDES	(22) OV SPECIE	(23) NET GROSS	(24) ORIG VOL	(25) ORIG BA
Call Creek 5	1840	773	42	NE,2	1	1	2	74	46	205
Call Creek 6	2100	630	30	SE,2	2	1	6	64	19	81
Clark Creek	2640	1531	58	SW,1	3	2	8	80	27	117
Francis Creek 1	1267	405	32	SW,1	2	2	8	76	27	143
Francis Creek 2	3400	1088	75	SE,2	2	2	8	57	29	151
Harrington Creek 9	1640	705	43	SE,2	2	2	6	66	19	110
Harrington Creek 10	2300	207	9	SE,2	2	1	4	71	14	58
Jim Creek	3273	458	14	SE,2	4	2	6	69	84	304
Lovegren	600	282	47	NW,1	2	2	8	80	37	118
Mace Creek	1584	808	51	NW,1	2	1	8	77	29	100
Tin Cup Creek	700	98	14	SE,2	3	2	4	80	75	220
Unamed Creek	0	0	0	NE,2	3	1	6	54	9	37
Bull Frog Pond	600	60	10	NE,2	4	2	1	80	5	50

APPENDIX 4 (cont.)

Unit: North Umpqua Forest

	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
Buffer Name	VOL TREE	NO. STEMS	LOG DAM	%DF	%WH	%TF	%WRC	TOT VOL	VOL REM	VOL* REM	Vol down
Call Creek 5	1.15	40	3	81	11	0	8	51M	100.0	100.0	0.0
Call Creek 6	0.88	21	0	31	37	0	32	15M	69.5	63.9	30.5
Clark Creek	0.70	39	11	0	68	0	32	43M	89.0	67.2	11.1
Francis Creek 1	0.47	58	11	18	79	0	3	119M	88.0	77.0	12.0
Francis Creek 2	0.57	51	1	14	18	0	68	60M	94.9	83.2	5.1
Harrington Creek 9	0.98	30	3	48	30	0	22	106M	91.0	85.9	9.0
Harrington Creek 10	0.61	23	1	58	31	0	11	23M	98.0	98.0	2.0
Jim Creek	1.71	49	6	48	8	0	44	155M	59.0	59.0	41.0
Lovegren	0.87	43	4	0	72	0	28	34M	99.4	86.4	0.6
Mace Creek	0.76	38	5	0	97	0	3	23M	99.1	99.6	0.1
Tin Cup Creek	3.20	23	15	58	40	0	2	234M	82.5	75.0	17.5
Unamed Creek	0.40	27	0	37	7	0	56	5M	100.0	90.0	0.0
Bull Frog Pond	0.25	66	0	0	0	0	15	——	100.0	100.0	0.0

(85% hardwoods)

APPENDIX 4 (cont.)

Unit: North Umpqua Forest

Buffer Name	(37) Vol dead	(38) Vol dying	(39) ACD	(40) Buff shade	(41) AVHT ALL	(42) AVHT TALL	(43) NO. TALL	(44) NO. SMALL	(45) Number of winters
Call Creek 5	0.0	0.0	65	no	96	125	7	19	5
Call Creek 6	5.6	0.0	32	yes	108	117	1	4	4
Clark Creek	16.3	5.4	15	yes	95	121	1	22	3
Francis Creek 1	0.0	11.0	40	yes	93	116	1	34	7
Francis Creek 2	11.2	0.5	41	yes	95	110	0	24	7
Harrington Creek 9	2.5	2.6	66	yes	105	123	3	10	3
Harrington Creek 10	0.0	0.0	35	yes	90	142	1	17	3
Jim Creek	0.0	0.0	71	yes	127	141	11	12	1
Lovegren	11.2	1.8	63	yes	103	129	1	20	3
Mace Creek	0.3	0.0	23	yes	110	135	2	22	3
Tin Cup Creek	2.2	5.2	65	yes	125	148	7	7	4
Unamed Creek	10.0	0.0	70	no	76	0	0	23	4
Bull Frog Pond	0.0	0.0	—	—	66	0	0	59	4

APPENDIX 5

OVER THE WINTER VOLUME LOSS SUMMARY FOR SAMPLE VOLUMES

Unit: Willamette Forest

Buffer Name	1975 living	1976 living	chng	1975 down	1976 down	chng	1975 dead	1976 dead	chng	1975 dyng	1976 dyng	chng
Black Creek	198	198.0	0.0	0.0	0.0	0.0	11	11	0	0.5	0.5	0
Blowout Creek	155	150.0	5.0	0.5	5.5	5.0	0	0	0	0.0	0.0	0
Cadenza Creek	24	24.0	0.0	0.8	0.8	0.0	0	0	0	0.3	0.3	0
Canal Creek	140	126.0	14.0	16.0	30.0	14.0	0	0	0	4.0	4.0	0
Cook Creek	130	130.0	0.0	0.0	0.0	0.0	0	0	0	4.0	4.0	0
Davey Creek	108	60.6	47.4	11.0	58.4	47.4	0	0	0	0.0	0.0	0
Deer Creek	146	146.0	0.0	8.0	8.0	0.0	2	2	0	3.0	3.0	0
Hardy Creek 1	205	190.0	15.0	4.0	19.0	15.0	0	0	0	2.0	2.0	0
Hardy Creek 2	142	142.0	0.0	25.0	25.0	0.0	0	0	0	3.0	3.0	0
Lost Creek	91	91.0	0.0	2.0	2.0	0.0	4	4	0	0.0	0.0	0
Owl Creek	126	97.0	29.0	36.0	65.0	29.0	0	0	0	3.0	3.0	0
Perdue Creek	184	184.0	0.0	0.0	0.0	0.0	0	0	0	4.0	4.0	0
Rider Creek	61	61.0	0.0	45.0	45.0	0.0	0	0	0	0.0	0.0	0
Tidbits Creek	80	80.0	0.0	9.0	9.0	0.0	0	0	0	10.0	10.0	0
page total	1790	1679.6	110.4	157.3	267.7	110.4	17	17	0	33.8	33.8	0

APPENDIX 5 (cont.)

Unit: Willamette Forest

Buffer Name	1975 living	1976 living	chng	1975 down	1976 down	chng	1975 dead	1976 dead	chng
Two-Girls Creek	76.0	76.0	0.0	9.0	9.0	0.0	3.0	3.0	0.0
Winberry Creek	70.0	70.0	0.0	39.0	39.0	0.0	0.0	0.0	0.0
Wolf Creek 1	41.0	41.0	0.0	3.0	3.0	0.0	1.0	1.0	0.0
Wolf Creek 2	10.0	10.0	0.0	2.0	2.0	0.0	0.4	0.4	0.0
page total	197.0	197.0	0.0	53.0	53.0	0.0	4.4	4.4	0.0
grand total	1987.0	1876.6	110.4	210.3	320.7	110.4	21.4	21.4	0.0
% of original vol.	87.7	82.8	4.9	9.3	14.1	4.9	0.9	0.9	0.0
plus new buffer strips cruised summer 1976									
Elk Creek	208.0	111.0	97.0	42.0	139.0	97.0	13.0	13.0	0.0
(assume 30% of windthrow before 1976)									
Wolf Creek 3	188.0	94.0	94.0	0.0	94.0	94.0	0.0	0.0	0.0
grand total, all buffer strips	2383.0	2081.6	301.4	252.3	553.7	301.4	34.4	34.4	0.0
% of original vol.	87.7	76.6	11.1	9.3	20.4	11.1	1.3	1.3	0.0

APPENDIX 5 (cont.)

Unit: Willamette Forest

Buffer Name	1975 dying	1976 dying	chng
Two-Girls Creek	7.0	7.0	0.0
Winberry Creek	0.0	0.0	0.0
Wolf Creek 1	7.0	7.0	0.0
Wolf Creek 2	0.0	0.0	0.0
page total	14.0	14.0	0.0
grand total	47.8	47.8	0.0
% of original volume	2.1	2.1	0.0
plus new buffer strips cruised summer 1976			
Elk Creek	1.1	1.1	0.0
(assume 30% of windthrow before 1976)			
Wolf Creek 3	0.0	0.0	0.0
grand total, all buffer strips	48.8	48.8	0.0
% of original volume	1.8	1.8	0.0

APPENDIX 5 (cont.)

Unit: Mt. Hood Forest

Buffer Name	1975 living	1976 living	chng	1975 down	1976 down	chng	1975 dead	1976 dead	chng
Bear Creek	17.0	17.0	0.0	9.0	9.0	0.0	41.0	41.0	0.0
Bedrock Creek	148.0	148.0	0.0	23.0	23.0	0.0	3.0	3.0	0.0
Blister Creek	105.0	104.5	0.5	0.0	0.0	0.0	3.0	3.5	0.5
Bull Run River	145.0	123.0	22.0	80.0	102.0	22.0	2.0	2.0	0.0
N. Fork Bull Run	36.0	36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Whetstone Creek	51.0	51.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
grand total	502.0	479.5	22.5	112.0	134.0	22.0	49.0	49.5	0.5
% of original vol.	74.8	71.5	3.3	16.7	20.0	3.3	7.3	7.4	0.1
plus new buffer strips cruised during summer 1976									
S. Fork Clackamas	208.0	47.0	161.0	0.0	161.0	161.0	0.0	0.0	0.0
grand total all buffer strips	710.0	526.5	183.5	112.0	295.0	183.0	49.0	49.5	0.5
% of original vol.	80.8	59.9	20.9	12.7	33.6	20.8	5.6	5.6	0.1

APPENDIX 5 (cont.)

Unit: Mt. Hood Forest

Buffer Name	1975 dying	1976 dying	chng
Bear Creek	4.0	4.0	0.0
Bedrock Creek	4.0	4.0	0.0
Blister Creek	0.0	0.0	0.0
Bull Run River	0.0	0.0	0.0
N. Fork Bull Run	0.0	0.0	0.0
Whetstone Creek	0.0	0.0	0.0
grand total	8.0	8.0	0.0
% of original vol.	1.2	1.2	0.0
plus new buffer strips cruised during summer 1976			
S. Fork Clackamas	0.0	0.0	0.0
grand total all buffer strips	8.0	8.0	0.0
% of original vol.	0.9	0.9	0.0

APPENDIX 5 (cont.)

Unit: North Umpqua Forest

Buffer Name	1975 living	1976 living	chng	1975 down	1976 down	chng	1975 dead	1976 dead	chng	1975 dyng	1976 dyng	chng
Call Creek 5	27.7	27.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Call Creek 6	9.6	8.4	1.2	2.8	4.0	1.2	0.7	0.7	0.0	0.0	0.0	0.0
Francis Creek 1	22.8	22.8	0.0	1.4	1.4	0.0	0.1	0.1	0.0	3.0	3.0	0.0
Francis Creek 2	22.3	22.3	0.0	3.5	3.5	0.0	3.1	3.1	0.0	0.0	0.0	0.0
Harrington Creek 9	60.1	54.8	5.3	0.4	5.7	5.3	1.6	1.6	0.0	1.6	1.6	0.0
Harrington Creek 10	10.0	10.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unamed Creek	2.5	2.5	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0
Bull Frog Pond	no significant commercial volume											
page total	155.0	148.5	6.5	8.3	14.8	6.5	5.8	5.8	0.0	4.6	4.6	0.0

APPENDIX 5 (cont.)

Unit: North Umpqua Forest

Buffer Name	1975 livng	1976 livng	chng	1975 down	1976 down	chng	1975 dead	1976 dead	chng	1975 dyng	1976 dyng	chng
Tin Cup Creek	124.0	101.0	23.0	0.0	23.0	23.0	3.0	3.0	0.0	7.0	7.0	0.0
Mace Creek	16.8	16.8	0.0	0.0	0.0	0.0	3.0	3.0	0.0	0.0	0.0	0.0
page total	140.8	117.8	23.0	0.0	23.0	23.0	6.0	6.0	0.0	7.0	7.0	0.0
grand total	295.8	266.3	29.5	8.3	37.8	29.5	11.8	11.8	0.0	11.6	11.6	0.0
% of original vol.	90.3	81.3	9.0	2.5	11.5	9.0	3.6	3.6	0.0	3.5	3.5	0.0
plus new buffer strips cruised summer 1976												
Clark Creek	24.0	24.0	0.0	4.0	4.0	0.0	6.0	6.0	0.0	2.0	2.0	0.0
Jim Creek	75.0	44.0	31.0	0.0	31.0	31.0	0.0	0.0	0.0	0.0	0.0	0.0
Lovegren Sale	23.0	23.0	0.0	0.0	0.0	0.0	3.0	3.0	0.0	0.0	0.0	0.0
grand total all buffer strips	417.8	357.3	60.5	12.3	72.8	60.5	20.8	20.8	0.0	13.6	13.6	0.0
% of original vol.	89.9	76.9	13.0	2.6	15.6	13.0	4.5	4.5	0.0	2.9	2.9	0.0

APPENDIX 6

OVER THE WINTER VOLUME LOSS SUMMARY FOR TOTAL VOLUMES

Unit: Willamette Forest

Buffer Name	1975 living	1976 living	chng	1975 down	1976 down	chng	1975 dead	1976 dead	chng	1975 dyng	1976 dyng	chng
Black Creek	594	594	0	0.0	0.0	0	33.0	33.0	0	1.5	1.5	0
Blowout Creek	295	285	10	1.0	11.0	10	0.0	0.0	0	0.0	0.0	0
Cadenza Creek	30	30	0	1.0	1.0	0	0.0	0.0	0	0.4	0.4	0
Canal Creek	221	199	22	25.0	47.0	22	0.0	0.0	0	6.3	6.3	0
Cook Creek	234	234	0	0.0	0.0	0	0.0	0.0	0	7.2	7.2	0
Davey Creek	225	126	99	23.0	122.0	99	0.0	0.0	0	0.0	0.0	0
Deer Creek	256	256	0	14.0	14.0	0	3.5	3.5	0	5.4	5.4	0
Hardy Creek 1	431	399	32	8.4	40.4	32	0.0	0.0	0	4.2	4.2	0
Hardy Creek 2	170	170	0	30.0	30.0	0	0.0	0.0	0	3.6	3.6	0
Lost Creek	237	237	0	5.2	5.2	0	10.4	10.4	0	0.0	0.0	0
Owl Creek	302	233	69	86.0	155.0	69	0.0	0.0	0	7.2	7.2	0
Perdue Creek	217	217	0	0.0	0.0	0	0.0	0.0	0	4.7	4.7	0
Rider Creek	70	70	0	51.3	51.3	0	0.0	0.0	0	0.0	0.0	0
Tidbits Creek	112	112	0	12.6	12.6	0	0.0	0.0	0	14.0	14.0	0
page total	3394	3162	232	257.7	489.5	232	46.9	46.9	0	54.5	54.5	0

APPENDIX 6 (cont.)

Unit: Willamette Forest

Buffer Name	1975 living	1976 living	chng	1975 down	1976 down	chng	1975 dead	1976 dead	chng
Two-Girls Creek	152.0	152.0	0.0	18.0	18.0	0.0	6.0	6.0	0.0
Winberry Creek	106.0	106.0	0.0	62.0	62.0	0.0	0.0	0.0	0.0
Wolf Creek 1	113.0	113.0	0.0	8.0	8.0	0.0	3.0	3.0	0.0
Wolf Creek 2	12.0	12.0	0.0	2.4	2.4	0.0	0.5	0.5	0.0
page total	383.0	383.0	0.0	90.4	90.4	0.0	9.5	9.5	0.0
grand total	3777.0	3545.0	232.0	347.9	579.9	232.0	56.4	56.4	0.0
% of original vol.	88.5	83.0	5.4	8.1	13.6	5.4	1.3	1.3	0.0
plus new buffer strips cruised summer 1976									
Elk Creek (assume 30% of windthrow before 1976)	374.0	200.0	174.0	76.0	250.0	174.0	23.4	23.4	0.0
Wolf Creek 3	517.0	259.0	258.0	0.0	258.0	258.0	0.0	0.0	0.0
grand total, all buffer strips	4668.0	4004.0	664.0	423.9	1087.9	664.0	79.8	79.8	0.0
% of original vol.	88.7	76.1	12.6	8.1	20.7	12.6	1.5	1.5	0.0

APPENDIX 6 (cont.)

Unit: Willamette Forest

Buffer Name	1975 dying	1976 dying	chng
Two-Girls Creek	14.0	14.0	0.0
Winberry Creek	0.0	0.0	0.0
Wolf Creek 1	19.0	19.0	0.0
Wolf Creek 2	0.0	0.0	0.0
page total	33.0	33.0	0.0
grand total	87.5	87.5	0.0
% of original vol.	2.0	2.0	0.0
plus new buffer strips cruised summer 1976			
Elk Creek	1.8	1.8	0.0
(assume 30% of wind-throw before 1976)			
Wolf Creek 3	0.0	0.0	0.0
grand total all buffer strips	89.3	89.3	0.0
% of original vol.	1.7	1.7	0.0

APPENDIX 6 (cont.)

Unit: Mt. Hood Forest

Buffer Name	1975 living	1976 living	chng	1975 down	1976 down	chng	1975 dead	1976 dead	chng
Bear Creek	37.0	37.0	0.0	20.0	20.0	0.0	90.0	90.0	0.0
Bedrock Creek	342.0	342.0	0.0	53.0	53.0	0.0	7.0	7.0	0.0
Blister Creek	252.0	250.8	1.2	0.0	0.0	0.0	7.0	8.2	1.2
Bull Run River	174.0	148.0	26.0	96.0	122.0	26.0	2.4	2.4	0.0
N. Fork Bull Run	79.0	79.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Whetstone Creek	71.0	71.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
grand total	955.0	927.8	27.2	169.0	195.0	26.0	106.4	107.6	1.2
% of original vol.	76.5	74.3	2.2	13.5	15.6	2.1	8.5	8.6	0.1
plus new buffer strips cruised during summer 1976									
S. Fork Clackamas	998.0	226.0	772.0	0.0	772.0	772.0	0.0	0.0	0.0
grand total for all buffer strips	1953.0	1153.8	799.2	169.0	967.0	798.0	106.4	107.6	1.2
% of original vol.	86.9	51.3	35.6	7.5	43.0	35.5	4.7	4.8	0.1

APPENDIX 6 (cont.)

Unit: Mt. Hood Forest

Buffer Name	1975 dying	1976 dying	chng
Bear Creek	9.0	9.0	0.0
Bedrock Creek	9.0	9.0	0.0
Blister Creek	0.0	0.0	0.0
Bull Run River	0.0	0.0	0.0
N. Fork Bull Run	0.0	0.0	0.0
Whetstone Creek	0.0	0.0	0.0
grand total	18.0	18.0	0.0
% of original vol.	1.4	1.4	0.0
plus new buffer strips cruised during summer 1976			
S. Fork Clackamas	0.0	0.0	0.0
grand total for all buffer strips	18.0	18.0	0.0
% of original vol.	0.8	0.8	0.0

APPENDIX 6 (cont.)

Unit: North Umpqua Forest

Buffer Name	1975 living	1976 living	chng	1975 down	1976 down	chng	1975 dead	1976 dead	chng	1975 dyng	1976 dyng	chng
Call Creek 5	51.0	51.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Call Creek 6	11.2	9.8	1.4	3.3	4.7	1.4	0.8	0.8	0.0	0.0	0.0	0.0
Francis Creek 1	106.4	106.4	0.0	6.5	6.5	0.0	0.5	0.5	0.0	14.0	14.0	0.0
Francis Creek 2	49.0	49.0	0.0	7.7	7.7	0.0	6.8	6.8	0.0	0.0	0.0	0.0
Harrington Creek 9	100.0	91.5	8.5	0.7	9.2	8.5	2.7	2.7	0.0	2.7	2.7	0.0
Harrington Creek 10	23.0	23.0	0.0	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unamed Creek	5.0	5.0	0.0	0.0	0.0	0.0	0.6	0.6	0.0	0.0	0.0	0.0
Bull Frog Pond	no significant commercial volume											
page total	345.6	335.7	9.9	18.7	28.6	9.9	11.4	11.1	0.0	16.7	16.7	0.0

APPENDIX 6 (cont.)

Unit: North Umpqua Forest

Buffer Name	1975 living	1976 living	chng	1975 down	1976 down	chng	1975 dead	1976 dead	chng	1975 dyng	1976 dyng	chng
Tin Cup Creek	227.0	185.0	42.0	0.0	42.0	42.0	5.5	5.5	0.0	12.8	12.8	0.0
Mace Creek	22.3	22.3	0.0	0.0	0.0	0.0	4.0	4.0	0.0	0.0	0.0	0.0
page total	249.3	207.3	42.0	0.0	42.0	42.0	9.5	9.5	0.0	12.8	12.8	0.0
grand total	594.9	543.0	51.9	18.7	70.6	51.9	20.9	20.9	0.0	29.5	29.5	0.0
% of original vol.	89.6	81.8	7.8	2.8	10.6	7.8	3.1	3.1	0.0	4.4	4.4	0.0
plus new buffer strips cruised summer 1976												
Clark Creek	28.3	28.3	0.0	5.0	5.0	0.0	7.0	7.0	0.0	2.0	2.0	0.0
Jim Creek	143.0	84.0	59.0	0.0	59.0	59.0	0.0	0.0	0.0	0.0	0.0	0.0
Lovegren Sale	30.0	30.0	0.0	0.0	0.0	0.0	4.0	4.0	0.0	0.0	0.0	0.0
grand total all buffer strips	796.2	685.3	110.9	23.7	134.6	110.9	31.9	31.9	0.0	31.5	31.5	0.0
% of original vol.	90.1	77.6	12.6	2.7	15.2	12.6	3.6	3.6	0.0	3.6	3.6	0.0