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The History of Fire in the Bull Run Watershed, Oregon

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Preface

This report was commissioned jointly by the City of Portland and the USDA Forest Service as part of a larger project investigating historical natural disturbances in the Bull Run Watershed near Portland, Oregon. The project has been a collaboration not only with these two funding institutions, but also involved scientists from three research institutions: the University of Washington, Oregon State University, and the USDA Forest Service. The portion of the study summarized here involves the history of fire in the watershed, and its interaction with other disturbances. It is intended that an integrated report will be produced that more fully summarizes the major disturbances, especially wind, and the synergistic interaction that disturbance has had over the centuries.

This project is the completion report for Supplemental Agreement PNW-92-0225 between the USDA Forest Service and the University of Washington.

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Introduction

Long before the Bull Run watershed was used as a major source of water for the Portland metropolitan area, it provided water into the Columbia River. The quantity and quality of water varied over these millennia, due to long-term climate change and shorter-term periods of wetter and drier weather. Another set of factors important in understanding the hydrology of the watershed is natural or human-induced disturbance, including fire and wind. The objective of this study to define the long-term history of wildfire in the Bull Run Watershed as part of a larger study integrating other aspects of landscape disturbance.

Background

The Bull Run watershed (Figures 1, 2) was included in 1891 as part of a national system of forest reserves in the United States. The Bull Run tends to have almost twice the precipitation of watersheds directly north and south, and was recognized early for its substantial runoff. Its legislative importance as a water source for the Portland Metropolitan area was established in 1892, when President Harrison established the Bull Run Reserve. The initial Bull Run supply system was completed in 1895. In 1904, President Teddy Roosevelt signed the Bull Run Trespass Act which offered further protection for the watershed as a municipal water supply beyond that provided by the Federal reserve designation. After 1958, a number of non-water resource management activities began in the basin, including recreation in outlying areas of the original Reserve boundary, and timber management. These activities continued until 1976, when court action enjoined further recreation and logging. In 1977, President Jimmy Carter signed

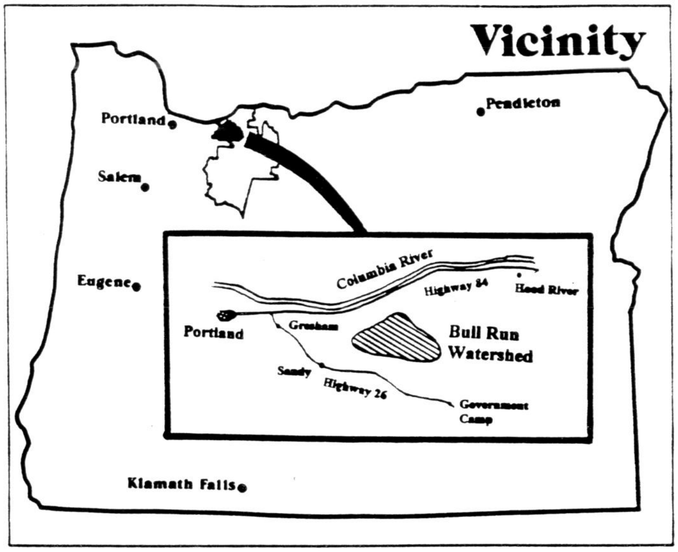


Figure 1. The Bull Run watershed is located in northwest Oregon on the Mt. Hood National Forest east of Portland. It drains into the Sandy River which empties into the Columbia River near Gresham.

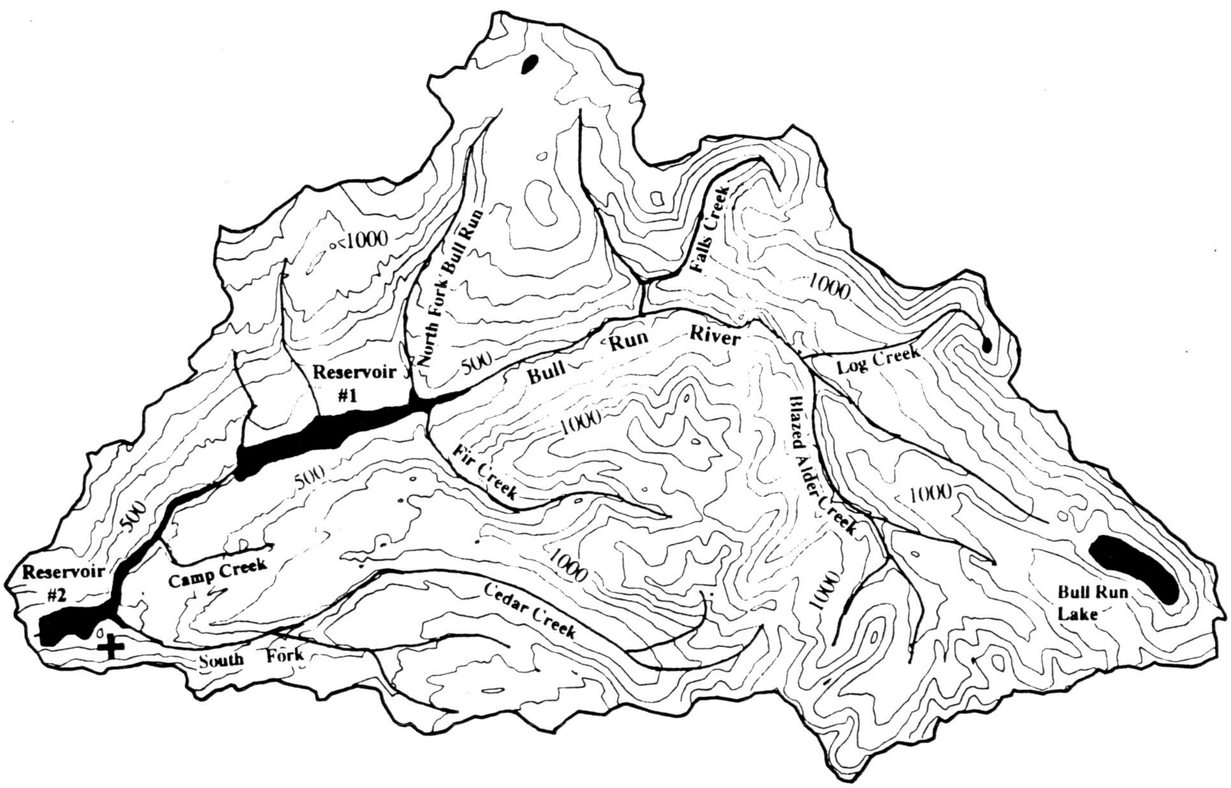


Figure 2. Topography and major features of the Bull Run watershed. Contours are 100 m intervals.

P.L. 95-200 establishing the Bull Run Watershed Management Unit with an objective of producing "...pure, clear, raw potable water...for the City of Portland and other local governmental units and persons in the Portland metropolitan area...". In 1983, a major windstorm entered the watershed and about 10 percent of the existing forest had significant timber blown down. Salvage logging was conducted on about 675 ha of the area affected by the 1983 windstorm. After the northern spotted owl (*Strix caurina occidentalis*) became a listed species under the Endangered Species Act in 1990, about 90 percent of the watershed became designated as a Late Successional Reserve by FEMAT (Federal Ecosystem Management Assessment Team), and adopted as part of President Clinton's Northwest Forest Plan (Thomas 1994). Timber harvest and salvage operations are severely restricted under the LSR designation of the Forest Plan, so that future water quality impacts will largely be due to natural disturbance patterns.

The idea that natural events might adversely affect water quality in the watershed began to raise interest in defining the natural disturbance regimes of the watershed. Issues included the effects of historic fire and wind in the watershed, and the degree to which natural disturbance patterns may be altered by human activity in or around the watershed. Some of these alterations include effects of wind on partially fragmented forests caused by past road or timber harvest activities, humans as sources of wildfires, and conditions under which fires of natural or human origin might spread through the watershed.

The Forests of the Bull Run

The forests of the Bull Run Watershed are similar to those elsewhere west of the Cascade Crest. There are three major forest zones (Franklin and Dyrness 1973) defined on the basis of potential vegetation that might eventually dominate that type in the long-term absence of disturbance. The most widespread is the *Tsuga heterophylla* (western hemlock) zone, occupying the lowest elevations in the watershed and covering the most area, particularly in the western half of the watershed. A crescent-shaped band of the western hemlock zone extends up the main fork of the Bull Run and adjacent slopes. The major species in this zone include western hemlock and Douglas-fir (*Pseudotsuga menziesii*), with western redcedar (*Thuja plicata*) and other species more locally important (Franklin and Dyrness 1973). Douglas-fir in this area is considered shade intolerant, so it usually becomes established only on disturbed sites where considerable growing space has been opened. It tends to be a widespread dominant after forest fires along with western hemlock (Agee 1993). Because Douglas-fir can live over 750 years (Waring and Franklin 1979), the occurrence of Douglas-fir age classes across the landscape serve as time markers of past forest disturbance. Western hemlock, as a shade tolerant species, can become established after fires, but may also establish well in small gaps locally created by individual tree falls. The widespread distribution of Douglas-fir in the *Tsuga heterophylla* zone suggest that past forest fires have affected much of this zone over the past millennium.

At higher elevations, the *Abies amabilis* (Pacific silver fir) zone is more widespread. Shade-tolerant species like western hemlock and Pacific silver fir will eventually dominate these sites if they are undisturbed for many centuries. Western hemlock may be a codominant at the lower fringe of the *Abies amabilis* zone, but it is generally not as successful at shedding accumulated winter needlefall in the spring as Pacific silver fir (Thornburgh 1969). Douglas-fir plays an ecological role similar to that at lower elevation, but is usually less dominant because of frost, cold soils, snow breakage as saplings, and generally cooler conditions favoring other species. Alaska yellow-cedar (*Chamaecyparis nootkatensis*) is occasionally found on wetter sites and tends to be a shade tolerant, late-successional codominant along with Pacific silver fir. The *Abies* *amabilis* zone covers most of the higher elevation area in the eastern portion of the watershed.

The highest elevation zone typically found in west Cascades forests is the *Tsuga mertensiana* (mountain hemlock) zone. This zone is uncommon in the Bull Run as it covers only a few sites in the vicinity of Bull Run Lake. It is the deep snow zone of the western Cascades and is better represented at elevations higher than those found in the Bull Run Watershed.

Fire in West Cascade Forests

Forest fires in the western Cascades have usually been described as infrequent, high intensity events that kill almost all the trees within the fire boundaries. Large scale events such as the Yacolt burn (1902) and the Tillamook burn (1933) have served as archetypes for all forest fires in the western Cascades. However, we know that fire can operate at a variety of scales and severities, and it can range over a spectrum of severities known as high, moderate, and low severity fire regimes (Agee 1993). The Yacolt and Tillamook burns are excellent examples of the high severity fire regime. Much of the wetter portion of the *Tsuga heterophylla* zone, and the *Abies amabilis* zone, are also in the high severity fire regime (Agee 1993). Small portions of the landscape in high severity fire regimes may burn with moderate or low severity. However, there are locally variant forests west of the Cascades crest where a moderate severity fire regime is the dominant fire regime, represented by more frequent (100 years or less) and less intense fires leaving substantial residual forest: the San Juan Islands (Agee and Dunwiddie 1984), and the Ross Lake area of the North Cascades (Agee et al. 1990). To the south of the Bull Run a more widespread pattern of moderate severity fire is evident, representing a gradient to drier forests (Means 1982, Teensma 1987, Morrison and Swanson 1990, Agee 1991). These studies identified a potentially broad range of fire regimes that might be applicable to the Bull Run.

In each of these studies, age classes of Douglas-fir were important in establishing the frequency and severity of the fire regime. Temporal distance between age classes helps to establish fire return intervals, and the dominance of the different age classes helps to establish what proportion of older age classes was killed by one or more previous fires. In the high severity fire regime, a single age class of Douglas-fir will be found at any single point, but may have a wide range (up to 75 years [Hemstrom and Franklin 1982]). Fire return intervals must be established by the proportion of landscape occupied by different age classes, and the high fire severity is derived by the relative absence of remnant trees.

In the moderate severity fire regime, one or more residual age classes will be present at most places on the landscape. High severity patches occur, but many places on the landscape are only thinned by fire, opening substantial growing space for Douglas-fir between the residual trees. Other places underburn with low intensity fire, and those patches may not have many large trees killed, so they may not be represented with post-fire age classes of Douglas-fir. They may have a post-fire cohort of more shade tolerant species, such as western hemlock or Pacific silver fir. The presence of Douglas-fir in one or more age cohorts usually is reliable as a fire indicator, but reliance on establishment of Douglas-fir to indicate a fire may underestimate the presence of very low intensity fires that might not be severe enough to open the canopy and result in successful Douglas-fir establishment.

Other disturbance events are also occurring on the landscape and may be confused with the effects of fire. Wind tends to be an important episodic event in the western Cascades area. Unlike fire, which tends to thin from below (e.g., kills smallest trees first, largest last), wind tends to thin from above, removing larger, exposed trees, and leaving smaller, protected ones. Often intermediate crown class trees are preferentially windthrown, but as the intensity of the event increases, it is the understory that is left. Usually these trees are shade tolerant (e.g., western hemlock and Pacific silver fir locally), and will show a substantial growth release when the overstory is removed, so that wind can be differentiated from fire in stand reconstructions.

The species composition and structure of the forests of today therefore hold many secrets to the past. It is possible to reconstruct many disturbance types and events of past times by recognizing the patterns and spatial extent of various species composition and structure across the landscape. This approach is the basis for the fire history of the Bull Run Watershed.

Previous Fire History Work in the Bull Run

There are several sources of historical fire for the Bull Run and vicinity. In 1900, a forest type map of Oregon was produced by the U.S. Geological Survey (Gannett 1902). A redrafted portion of that map (Figure 3) shows substantial burned land in and around the Bull Run. Burned lands on these maps indicated stand replacement burns of the past half-century, so this is high severity burned area between 1850-1900. Lower severity burns would not be shown. The area shown as unburned included lands converted to agriculture or pasture, logged areas, young to old growth, and barren. Within the Bull Run, unburned lands are largely old growth. At the turn of the century, about half of Clackamas County south of the Bull Run was classified as "burned".

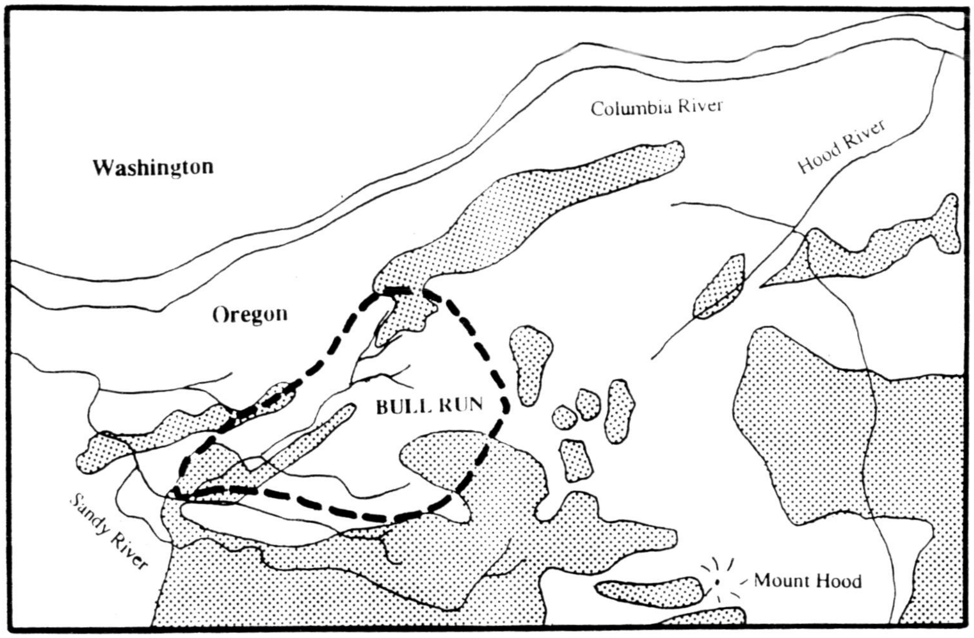


Figure 3. A redrawn map of the 1900 U.S. Geological Survey map of the forests of Oregon (Gannett 1902) showing the Bull Run area. Burned areas are stippled and indicate area where high severity burns had occurred within the 1850-1900 period. Because of poor topographic control available for maps of that time, fire and watershed boundaries shown are approximate.

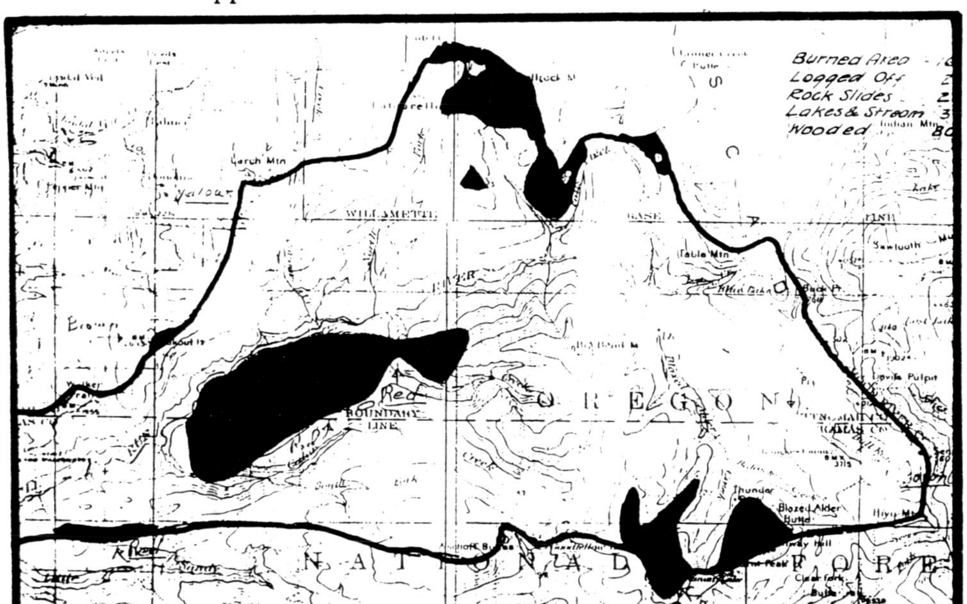


Figure 4. An early 20th century map (the Rotschy map?) showing burned areas in the Bull Run. Note the general similarity in burned areas to Figure 3.

A larger scale but anonymously authored map of burned lands in the Bull Run was produced early in the 20^{th} century (Figure 4). We located a copy of the map but no accompanying text. Pincha (1979) identifies such a map as being drafted by S. Rotschy in 1928, with burned areas having regeneration up to 40 years old. We speculate that the map reproduced in Figure 4 is the Rotschy map, and it is fairly consistent with the USGS map (Figure 3). The Pincha report includes a crude age class map of the watershed that is fairly consistent with the earlier maps except for showing more recent (post-1900) age classes northwest of the Bull Run River in the vicinity of the reservoirs. A followup to the Pincha report was a compilation of 20th century fires by Smith (1991, unpublished), who listed location, source, and size of recent fires and attempted map location of all of them.

All of these data sources suggest that much of the watershed consists of older forest unburned for centuries, a fair amount of younger forest in the western portion of the watershed initiated by late 19^{th} century fires, and little significant natural fire activity has occurred in the 20^{th} century.

Objectives

There were several objectives of the fire history portion of the Bull Run disturbance study:

1. Define the historical frequency of fire in the watershed.
2. Evaluate the fire regime (high or moderate severity).
3. Establish the seasonality of fire events.
4. Identify major synergistic effects between fire and other disturbances.

Methods

Fire Frequency

Methods to evaluate fire frequency include two general types: point frequencies and area frequencies. Point frequencies are commonly used in low severity fire regimes where fires are frequent and of low intensity. Many trees have multiple records of fire recorded on fire scars. In moderate to high severity fire regimes, fire-scarred trees are less common, but discrete forest age classes likely to have regenerated after fire will be found. Preliminary observations suggested that the Bull Run clearly fit in this latter category. Two types of area frequencies are used when forest age class data are available. The first, and the one used in this study, is called natural fire rotation (NFR). From the age class data and assumptions about reconstruction of past fire events, the area of individual past fire events is determined as a proportion of the total watershed area. The NFR is then determined by

$$\text{NFR} = \frac{\text{Time Period}}{\text{Proportion of Area Burned in Period}}$$

For example, in a 50,000 ha watershed, if 100,000 ha (proportion = 2.0) burned in a 400 year period, the NFR would be 400/2 = 200 years. A separate NFR can be calculated by plant community type, by century, by aspect, or any other temporal or geographic subset of the watershed. The NFR is a simple, easily understood technique, but has the major disadvantage of requiring the reconstruction of all past fire events. Further back in time, many of those events may have been partially, or sometimes wholly, erased from the landscape by subsequent fires. Therefore, the NFR becomes more conservative as one moves back in time.

The second area frequency technique is based on statistical distributions such as the Weibull or the negative exponential. Its major advantage is that it relies only on the current distribution of age classes, so that reconstruction of past events is not necessary. However, the use of these distributions assumes a monotonic flammability of stands of different ages (constant, or increasing over time, etc.) which has not been shown to be reliable for most temperate forests. It also assumes that ignition occurs randomly and is equally likely to occur in any stand, and that roughly equal areas burn over time. As such, it relies on an assumption of an equilibrium landscape that is unlikely to actually exist on the landscape. At Mount Rainier, Hemstrom and Franklin (1982) found the negative exponential model could not be fit to many of their watershed age class distributions because of large proportions of old age classes, creating a positive slope between age and the proportion of age classes, rather than the negative relationship of the negative exponential distribution.

In this study, the NFR technique was used, similar to the way it has been applied in other Pacific Northwest forests (Teensma 1987, Agee et al. 1990, Morrison and Swanson 1990, Agee 1991). Aerial photographs from 1957-58 and 1972 were used to delineate many stand boundaries, and used in conjunction with topographic maps to evaluate effects of slope and aspect on color and texture variation within an age class "patch". The set of rules applied in the reconstruction of fire events included:

1. **Uniformity**. The nature of vegetation responses to fire has not changed during the period covered by this study.
2. **Age continuity**. Trees in stands of similar age, separated by stands of younger age but not by significant topographic barriers, probably originated after the same fire episode.

Reconstruction of a fire event of the age of the older stands would therefore extend across the younger stand.

3. **Regeneration span**. Many stands had very short establishment periods and establishing a single date for the fire event was clear. Other stands had longer regeneration spans for early seral species, and Hemstrom and Franklin (1982) documented that some spans for Douglas-fir were 75 years or more. Regeneration spans of up to 75 years were accepted as a single event occurring at the beginning of the period as long as early seral regeneration was continuous and there were not increasing numbers of trees at the younger end of the cohort. Examples of age class interpretations are shown in Table 1.

4. **Topographic barriers**. Streams, ridgelines, and abrupt slope changes were used as fire boundaries unless stands on both sides had similar age class (regeneration) spans.

5. **Unsampled stands**. Unsampled stands identified on aerial photographs were age-dated based on nearby stands of similar color and texture on the aerial photographs.

A total of 208 plots were established in or directly adjacent to the 26,365 ha Bull Run watershed. At each plot, cohorts of Douglas-fir were visually identified by size. In previously harvested units, stump ages were counted in the field or removed with chain saws and returned to the lab for sanding and counting. Most logged units were in the oldest age classes because they had contained the highest volume. Most of the younger stands were sampled with increment corers, and we could obtain samples close to the pith in stands up to 250 years old with increment borers up to 75 cm long. These samples were placed in straws and returned to the lab where they were mounted in routed grooves and sanded until ring widths were clearly countable. Some cores were not near the pith due to the large size of the trees (e.g., in stands over 250 years old trees might be >2 m diameter) and core age corrections were made.

Table 1. Examples of tree ages collected from several sites with brief interpretations of identified cohorts (age groups).

Site	Species	Final Ages	Interpretation
104	Psme	91, 91, 91, 86, 86	This is a young, single-aged cohort. Very common.
120	Psme	586, 583, 580, 573	This is an old, single-aged cohort. Very common.
190	Psme Psme Tshe	499, 498 242 102, 101, 100, 97	This is a three-aged cohort, with the most recent fire of low severity, leaving enough residual canopy that only western hemlock survived. Unusual.
233	Abam Psme	249, 241, 232 94, 91, 90, 86	This is a two-aged cohort with Pacific silver fir forming the older cohort and an apparent patchy, low severity fire allowing a second cohort of Douglas-fir to establish. Unusual.
240	Psme Abpr Psme Abgr Psme	**410**, 403 355, **336**, **297** **308**, 266 **232**, **142**, **101** **89**, **88**	This appears to be a stand with multiple, confounding disturbances most likely involving wind and fire. Interpretation requires matching with adjacent sites, and use of more reliable core ages (in bold). Uncommon.

Psme = Douglas-fir, Tshe = western hemlock, Abam = Pacific silver fir, Abgr = grand fir, Abpr = noble fir.

Rings widths decline exponentially as age and distance from pith increase, due to ecological factors (shading, competition) and geometry (similar basal area increment on small and large trees result in wider and narrow annual increment, respectively). Estimates for correction were based on 25 cores selected from a range of five "slow growth" to "rapid growth" sites across the watershed. Ring widths for these trees were measured with a zoom microscope with an attached video monitor and a staging table accurate to 0.01 mm. The cores were measured to 140 mm out from the pith or 70 years, well beyond the corrections actually needed for sample cores. The resulting second-order equations (Figure 5), with associated rings/year ratios at different distances from the pith, were applied to individual samples by averaging the ten ring widths nearest to the center of the sample core and applying the best-fit equation to determine years to pith.

Estimated germination dates were calculated by adding several years to pith dates calculated or counted for stump or increment core samples (Figure 6). Because of the necessary age adjustments, not every sample was as reliable as the next. Age cohorts were defined on the basis of the best samples at each site: where the fewest years had to be added to obtain an origin date and where consistent origin dates were obtained on multiple samples (Table 1). Stands were then assigned cohort origin dates (one or more per site) based on reliable tree ages, primarily of the Douglas-fir cohorts if they were present on the site, and together with the stand boundary delineations, fire events were reconstructed. The data allowed reconstructions back to roughly 750 years before present. However, due to the spatial extent of one large event about 500 years B.P., NFR calculations were not extended back beyond that date. Natural fire rotations were calculated by aspect, elevation, and by century.

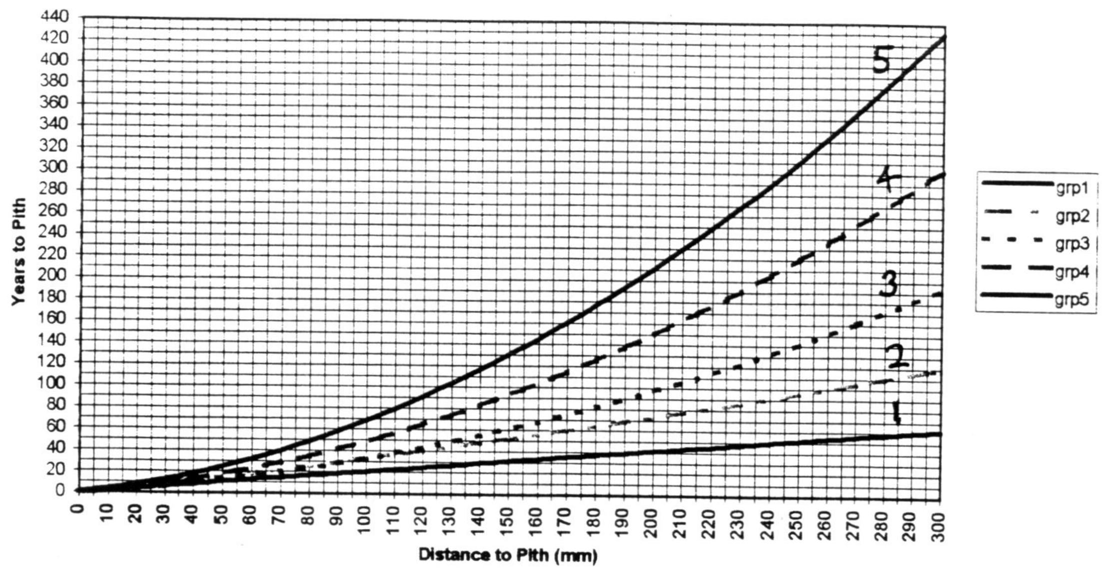


Figure 5. A graph of distance to pith vs. years to pith used to adjust increment core ages that did not reach the pith. The right side of the graph was never used but is included to visually show the separation between sites with fastest vs. slowest annual growth.

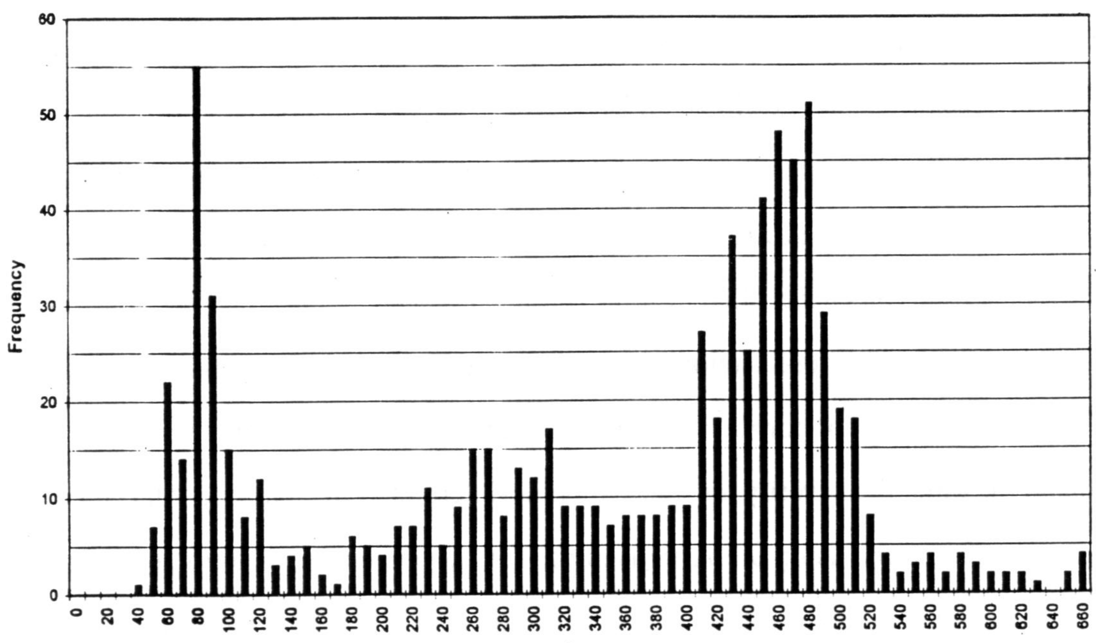


Figure 6. A histogram of tree ages from across the watershed, including increment cores and stumps. A clear concentration in three broad age classes (ca. 500, 300, and 100 years B.P.) is evident. The histogram is truncated and older trees (the 750 year age class) are omitted.

Fire Severity

Historical fire severity was analyzed using three independent sets of data. The first data set was age class information from the Forest Service Ecology Plots established in the Bull Run watershed between 1980 and 1992. The second data set consisted of the age class information collected for this project to determine fire frequency. The age class data were evaluated by attempting to identify relatively discrete Douglas-fir age classes individually by plot. If more than one age class was identified on a plot, then a multiple age class stand, and locally, a moderate severity fire pattern, was assumed to exist.

The third data set was photo-interpreted fire severity from three large fires that burned in the watershed after 1850 and before 1915. Three fires that burned in the 1850-1915 period were clearly evident on recent air photos by the uniform texture of the stand as viewed from above. The three fires chosen for analysis were (Figure 7) the Camp Creek fire, the Falls Creek fire, and the Hickman Butte fire. These fires were names for geographic locations where they burned and they did not necessarily originate in these locations. For the Camp Creek fire, only those portions south of the Bull Run River were analyzed, as the reservoirs have filled in some of the burned area. For the Falls Creek and Hickman Butte fires, only those sections of the fires within the Bull Run drainage were analyzed, leaving significant portions outside the analyzed area. These fires were outlined and the three fire severity levels were photo-interpreted by placing a 9 ha cell grid over orthophotos and using proportions of canopy coverage of younger/older forest within the 4 quadrants of each cell to determine fire severity level (low, moderate, high) at a 2.25 ha pixel scale. Differentiation of each cell to plant series at this scale was not attempted. The fire severity determinations at this scale were aggregated at this scale for analysis. The photo-interpretation of the Camp Creek fire was independently checked by two other observers.

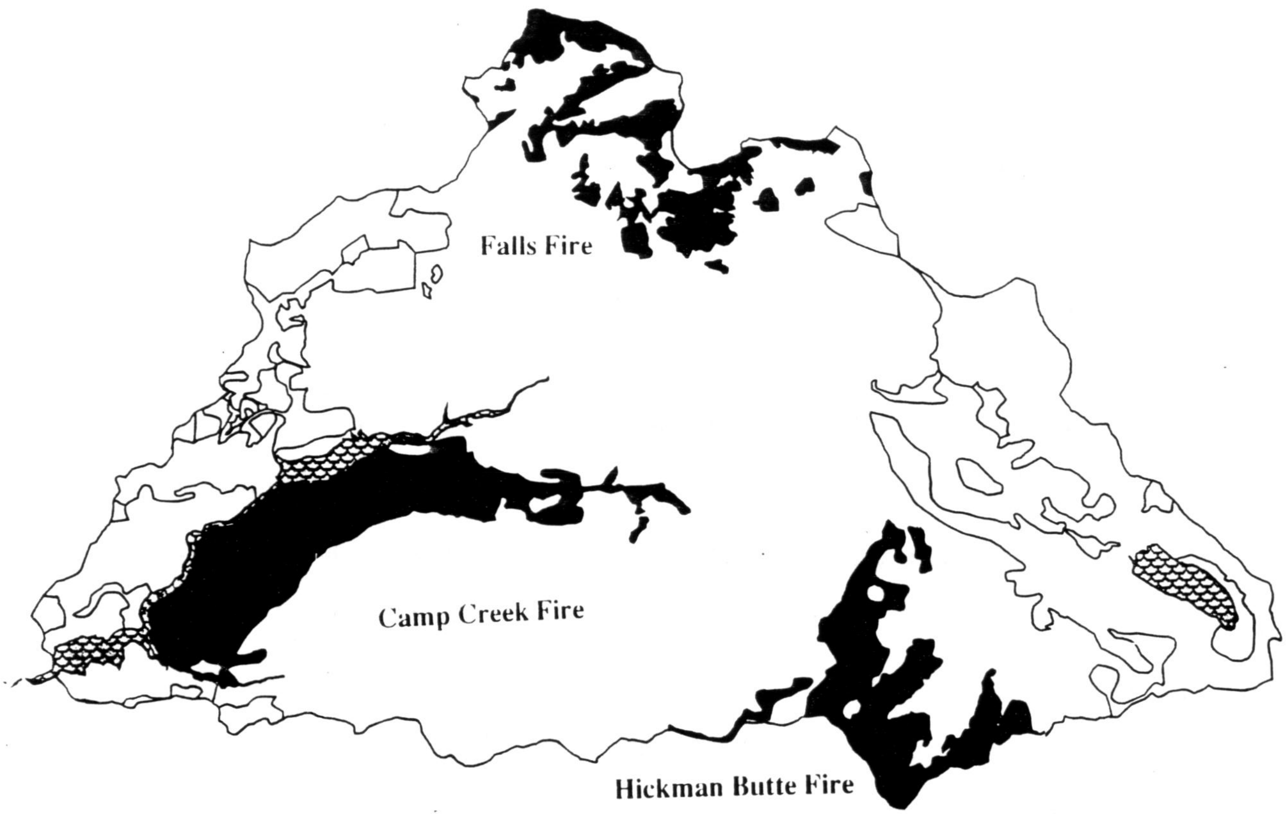


Figure 7. Location of the three fires used in photo-interpretation of fire severity. All three fires burned between 1850-1900.

A simple analysis of edge effect on fire severity was conducted by defining a 150 m edge (roughly 2 tree lengths) along each of the three fire boundaries within the Bull Run. The fire severity data was then re-aggregated by "edge" or "interior" to evaluate whether the proportions of fire severity levels differed by location. The interaction of edge and fire severity was tested with a Chi-square analysis.

There may be bias in photo-interpreting areas that burned with low severity fire, because it may not be very evident from aerial photos. The 1480 ha Camp Creek fire was intensively field-checked around its edges for the occurrence of low-intensity fire. A series of 15 transects was placed normal to the edge of the high severity fire zone, and the occurrence of residual trees and/or charcoal was measured away from the edge of the high severity fire zone. The edge of the moderate/low severity fire and the unburned forest was then drawn around the perimeter of the fire, and the area of this zone calculated and compared to the total fire area.

Fire Seasonality

There is no method available to establish the seasonality of the actual historic events in the Bull Run, but two alternate methods were employed to enable inferences about the seasonality of fire in the Bull Run watershed. The first was to evaluate the 20th century record, which was compiled by Pincha (1979) and mapped by Connie Smith of the Forest Service in 1991. She searched the records and mapped general locations of fires, along with their source (if known), size, and date of origin. The 20th century fire record in the Bull Run watershed is relatively limited and is to some extent incomplete. Some fires are identified only to year of occurrence. Fires before 1920 may not be recorded clearly, and the record is complete only to 1980. However, no large fires have occurred since 1980 so that this recent bias is small. The first technique was simply to aggregate the fires by month.

The second method of evaluating fire seasonality was to use a fire cycle model based on climate (Agee and Flewelling 1983) applied to a weather set from the Bull Run vicinity. This model was originally built for the Olympic Mountains but has been applied on a regional basis (Agee 1991, 1993). Based on 10-day increments from June 1 - September 30, the model predicts the probability of lightning ignitions based on long and short-term drought, thunderstorm activity, and east winds. The omission of fires starting in October probably underestimates fire activity in that month. The model does not provide a quantitative estimate of fire activity, but does allocate ignitions between months, and has been used effectively at a regional scale to evaluate fire regimes and seasonality. The proportions of fires by month that were likely to grow >1 ha in size were compared to the

20th century record of fires by month as a second way to evaluate the seasonality of fires in the Bull Run.

Fire Synergism

The major synergistic effect of fire in the Bull Run appears to be wind. When a fire "patch" is created, it tends to have at least some abrupt landscape edges. In that respect, local acceleration of subsequent windthrow may occur, particularly on the lee boundaries of the openings. This hypothesis is consistent with the abundant literature on wind impacts after patch cutting, but has not been established for natural disturbances such as wildfires that may create abrupt stand edges. We evaluated this potential impact on one fire just south of the Bull Run River known as the Camp Creek fire.

The effect of edge orientation and aspect to the major damaging winds on expansion of the fire patch was tested by placing 15 transects at various orientations to wind (southwest, northwest, northeast and southeast edges of the fire) and along several microtopographic aspects (northeast-facing, southwest-facing, and northwest/southeast [a direction of little significant wind]). Transects began at the edge of the high severity fire and continued into unburned forest past any evident windthrow associated with the edge. Each 40 m a 20 X 20 m plot was established, and 10 trees (2 nearest to each corner and 2 nearest to the plot center) were cored to establish post-fire and post-windthrow establishment and growth release dates. The number of tip-up mounds, their direction, and decay class, were recorded on a 30 X 30 m plot. The presence of tip-up mounds beyond the high severity fire edge was used to determine distance of subsequent windthrow into unburned forest or that burned with low severity. The design was incompletely sampled because of projected additional funding that failed to materialize, so some combinations of edge/aspect were not sampled or analyzed. Statistical analyses were confined to one-way analysis of variance, which increased the error term over a more powerful 2-way analysis of variance.

Results

Fire Frequency

The Bull Run appears to burn infrequently, and contains a large proportion of old growth forest as a result. Major fire events (Figure 8 A-H) are summarized below, and dates listed are approximate rather than precise to the year, particularly for those events 200 years or more B.P.

1243 A.D. The remnant stands (130 ha) from this event (Figure 8A, diagonal stripe patterns in two small blocks, one near the center of the watershed and near the south edge) are located near Big Bend Mountain and on the ridge southwest of upper Cedar Creek. Large Douglas-firs are present, along with Pacific silver fir, Alaska yellow-cedar, and western hemlock. Many of the trees have candelabra (multiple) tops, representing minor wind damage of the past. The two stands are separated by about 4 km, and if they represent a single event 750 years ago, most of the evidence has been erased by more recent fires. This event could have been large, but can only be shown as two small inclusions within the large 1493 event. This event was not used in reconstruction of natural fire rotation calculations because its extent could not be accurately reconstructed, and events between then and the 1493 fire were also erased. The presence of these oldest stands on ridgetops rather than in valleys is unusual, in that ridgetops tend to be less common as topographic refugia than valley bottoms.

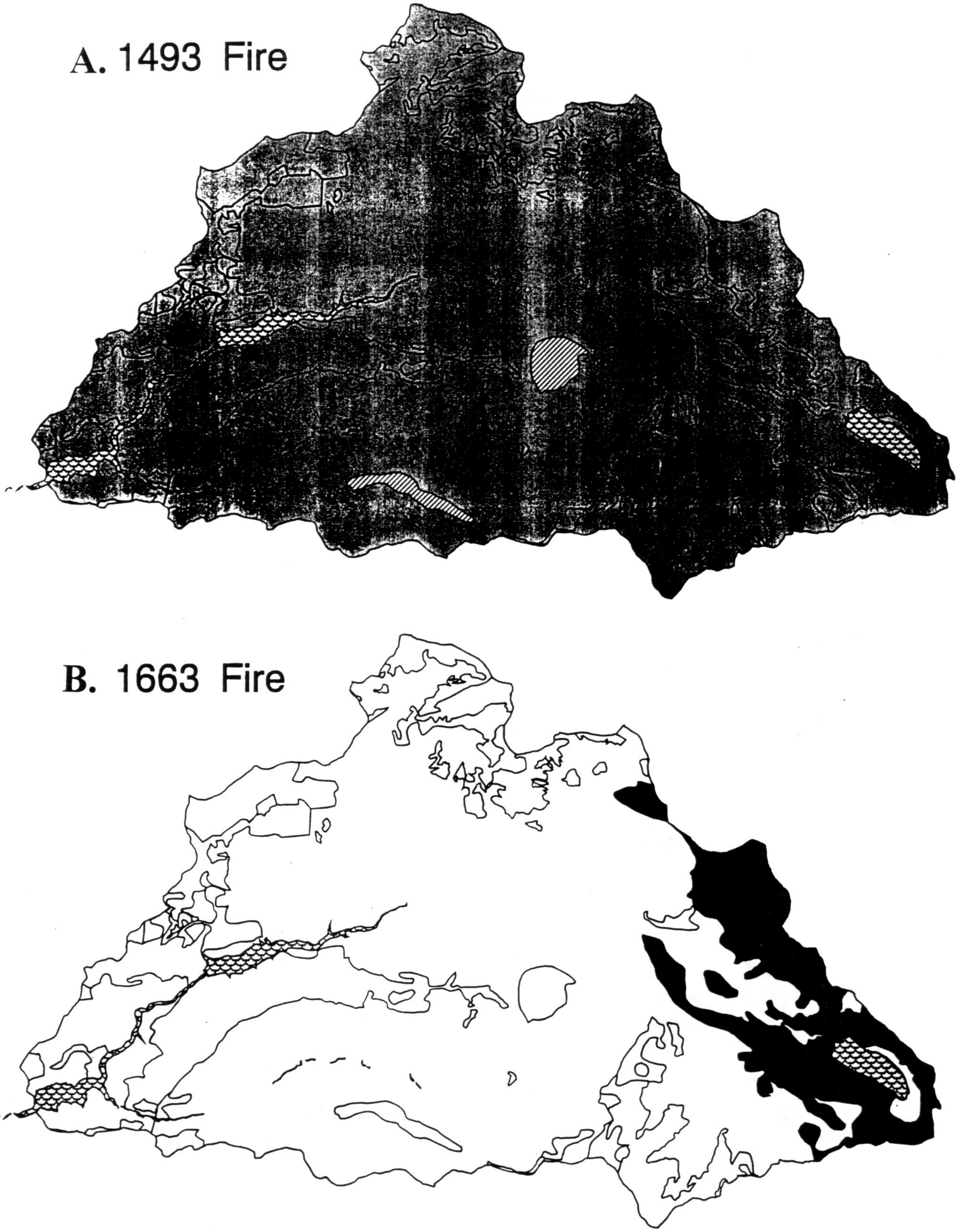
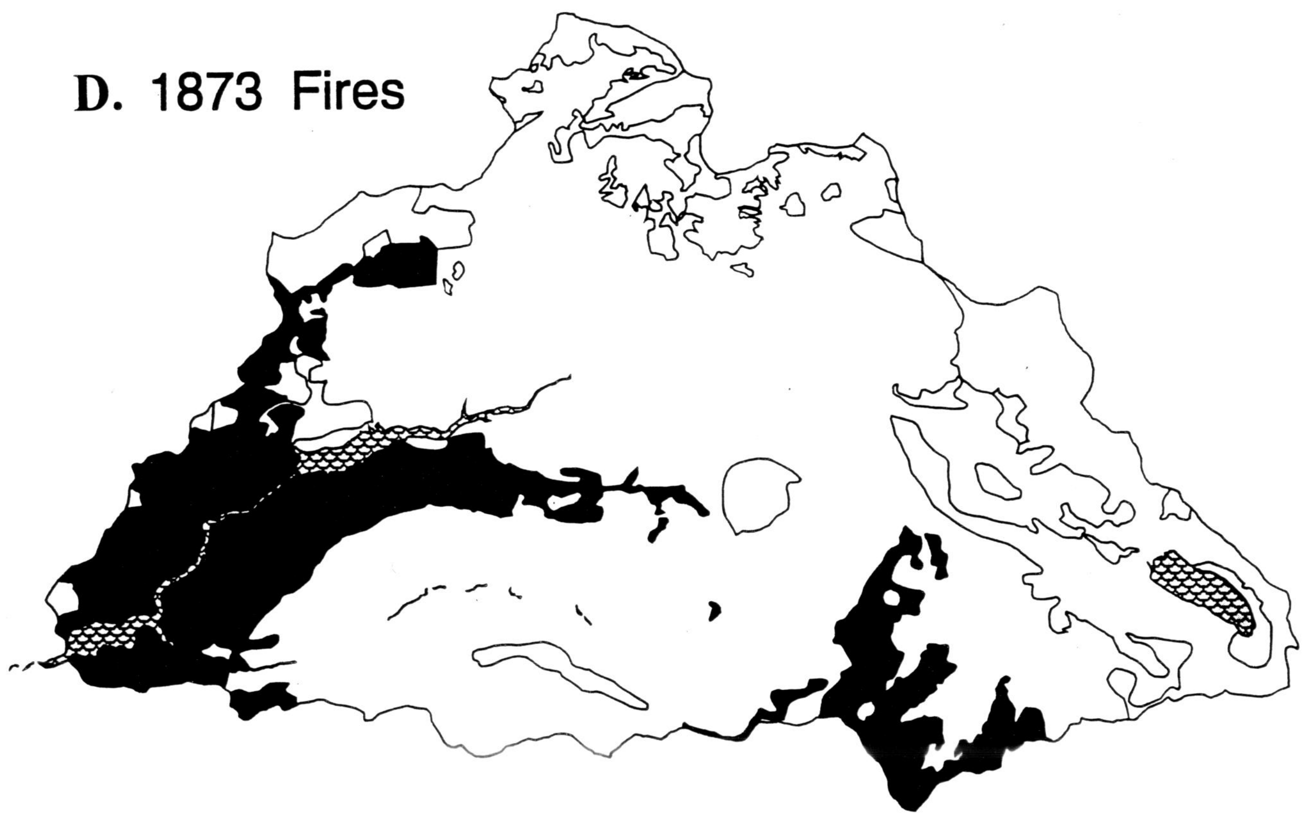


Figure 8. Reconstructed fire events in the Bull Run watershed.

C. 1693 Fire

D. 1873 Fires



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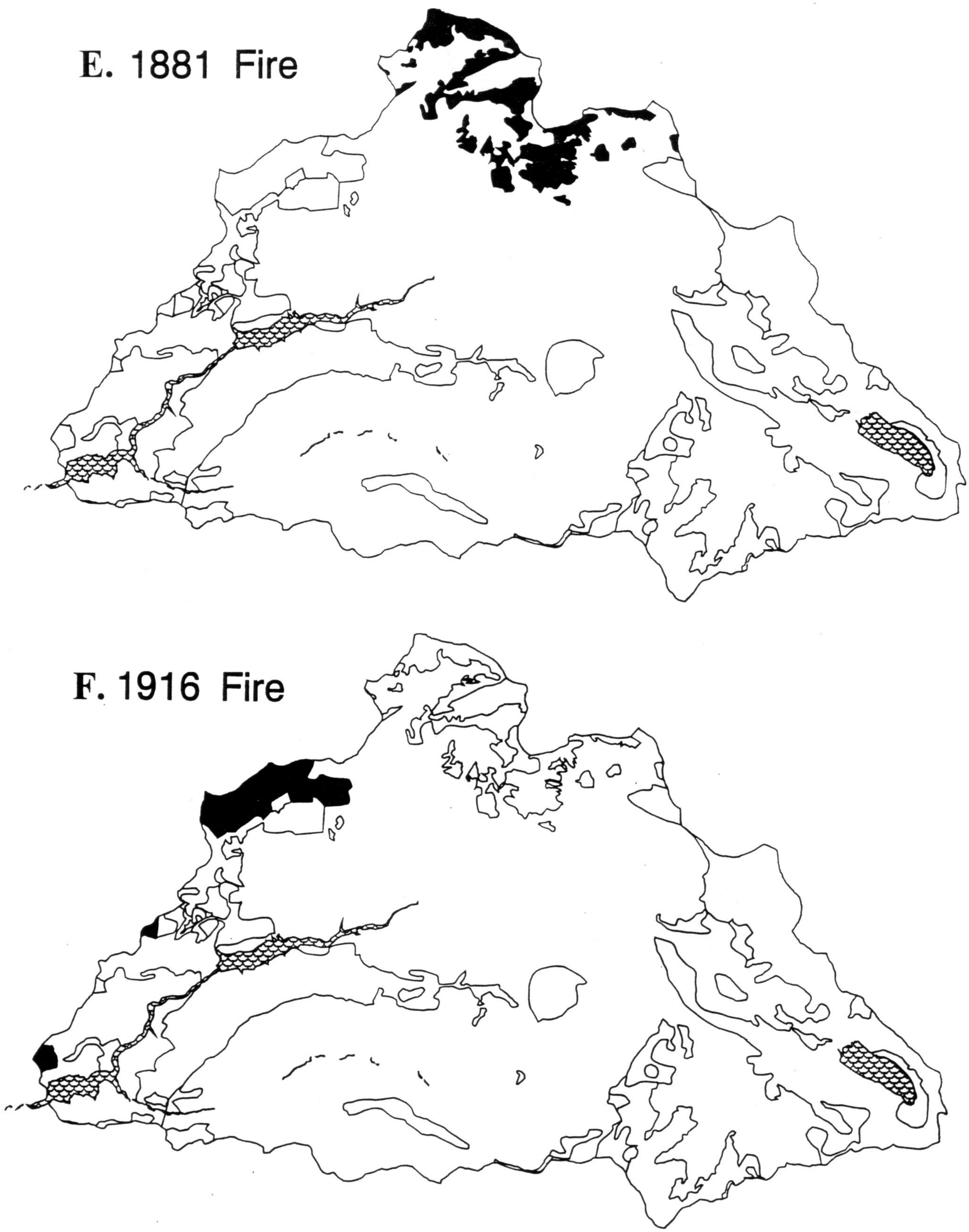

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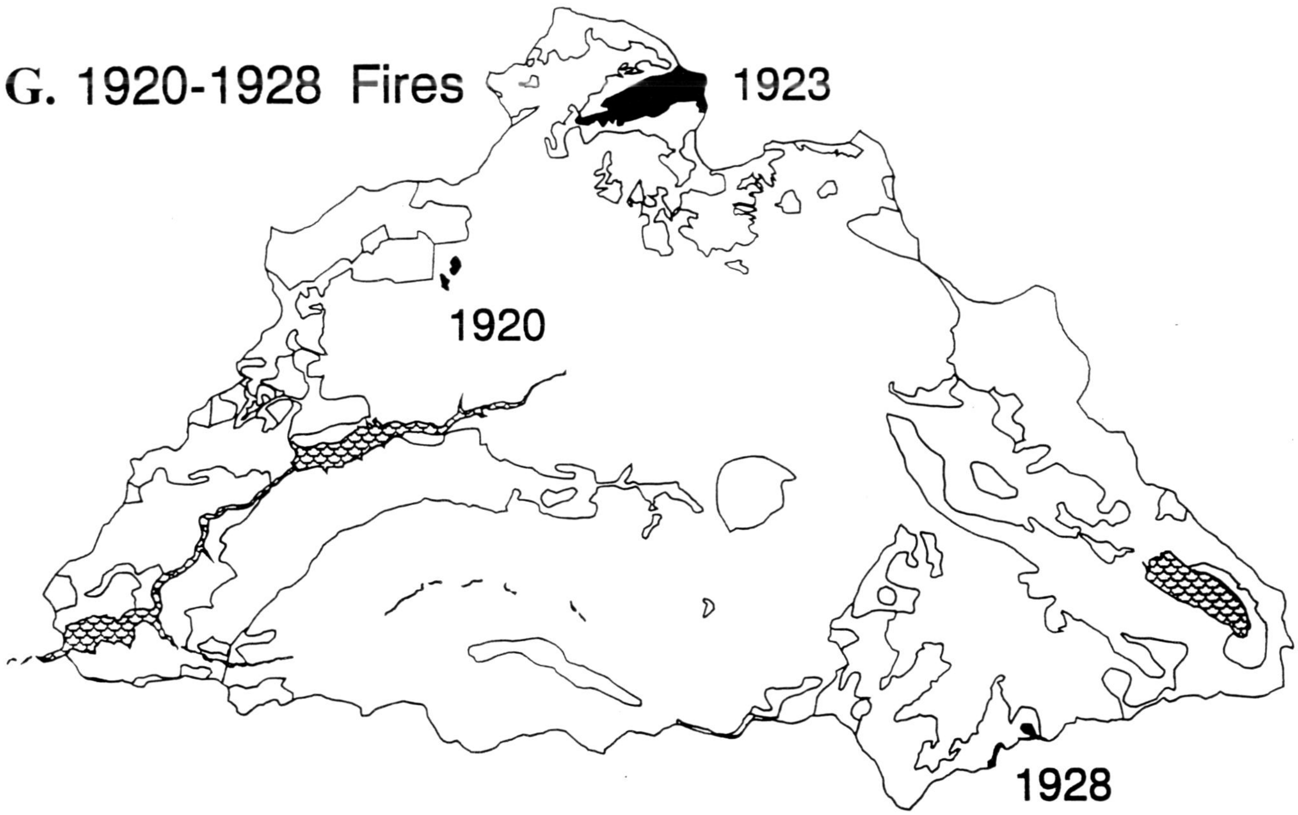

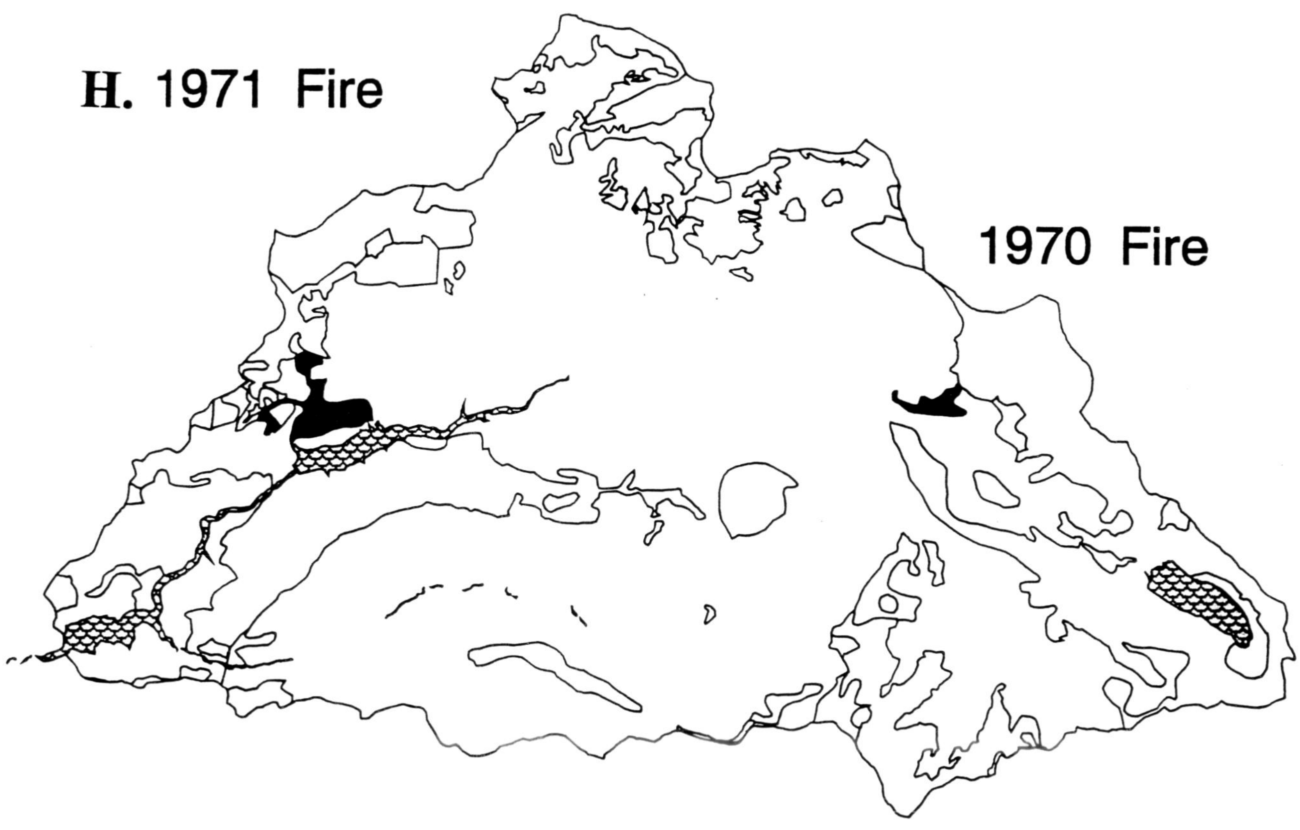

Figure 8 (continued).

1493 A.D. This reconstructed event (Figure 8A) is the largest single fire event to burn in the watershed, covering over 26,000 ha. Occurring about 500 years ago, it now forms the single largest age class in the watershed, and is usually the remnant age class in multiple-aged stands. It occurs from the head of the watershed to the east all the way across down to the lowlands on the west. The only portion of the watershed that did not burn are the remnant 750 year old stands. Most of the more recent fire events are etched into a matrix of this 500 year old set of forest age classes.

1663 A.D. After the 1493 A.D. event, there appears to have been little fire activity for the next 150 years. The next large fire (>2800 ha) occurred in 1663 A.D. in the eastern portion of the watershed (Figure 8B), and most of the stands burned were contiguous to the watershed boundary to the northeast or to the south.

1693 A.D. The 1693 fire (Figure 8C) burned in the western portion of the watershed, and much of this area has reburned between then and the present. It was identified by the presence of scattered residuals over most of this landscape.

1873 A.D. Almost two centuries passed before the next large fire event (>2700 ha). It may have been two different fires, one burning the western lowland in the vicinity of Reservoir 2, and the other burning the boundary area in the vicinity of Hickman Butte and Thimble Mountain (Figure 8D). The latter fire is further analyzed for fire severity as the Hickman Butte fire. The long east-west burned area on the south is called the Camp Creek fire and is further analyzed for fire severity in another section of the report. The USGS map (Figure 3) shows these areas to be contiguously burned, as much of the area south of the watershed was burned in the same time period.

1881 A.D. A rather patchy fire burned in the north portion of the watershed in 1881 (Figure 8E). This fire has been named the Falls Creek fire and is further analyzed in the fire severity section of the report.

20th Century fires. A number of smaller, human-caused fire events (primarily escaped slash fires) could be identified in the 20th century (Figure 8F-H). Together they burned less than 2000 ha. They tend to be clustered in the northern portion of the watershed.

The overall NFR for the Bull Run watershed is 350 years (Table 2). The literal interpretation of this number means that every 350 years, an area equal in size to the watershed has burned. Obviously there is considerable variation in this number: NFR's calculated by century show a range from roughly 100 years for the century encompassing the 1493 fire event to centuries for which NFR's could not be calculated because of the absence of fire activity. Areas above 1000 m elevation generally burned more frequently than areas below 1000 m elevation. This elevation boundary is roughly equivalent to the boundary of the *Tsuga heterophylla/Abies amabilis* zones, and indicates that the *Abies amabilis* zone burns more often than the *Tsuga heterophylla* zone.

The natural fire rotation calculations are heavily weighted to fires of antiquity, which appear to have been very widespread across the watershed. The overall NFR of 350 years decreases to 299 years if the time period before 1900 is considered, and decreases to 267 years if only the period before 1800 is considered. The NFR's are so closely tied to individual fire events of these past centuries that it is not possible to consider these past centuries as examples of different equilibrium fire regimes. Rather, they appear to be centuries where somewhat aberrant, unusual conditions coalesced to produce widespread burning in a watershed that is typically not very flammable.

Table 2. Natural fire rotations for the Bull Run watershed. Individual NFR's are calculated by elevation, roughly at the break between the *Tsuga heterophylla* and *Abies amabilis* plant series, and by time period.

Time Period	Below 1000 m Elevation			Above 1000 m Elevation			All Elevations		
	Area	p	NFR	Area	p	NFR	Area	p	NFR
Total (1493-1993)	**28184**	**1.36**	**369**	**9498**	**1.70**	**293**	**37682**	**1.43**	**350**
15th Century	20729	1.00	99	5492	0.98	101	26221	0.99	101
16th Century	0	0	--	0	0	--	0	0	--
17th Century	1501	0.07	1371	2551	0.46	216	4052	0.15	667
18th Century	0	0	--	0	0	--	0	0	--
19th Century	4777	0.23	431	761	0.14	725	5538	0.21	476
20th Century	1177	0.06	1660	694	0.12	750	1871	0.07	1328
Before 1900	27007	1.30	312	8804	1.58	257	35811	1.36	299
Before 1800	22230	1.07	286	8043	1.44	212	30273	1.15	267

Natural fire rotations were also calculated for topographic aspects. North and east aspects had a NFR of 362 years, while south and west aspects had a NFR of 354 years. In the post-1800 era, south and west aspects have burned slightly more frequently than north and east aspects (734 vs. 827 years), probably because the areas burned have generally been concentrated in the northern portion of the watershed that has a generally south aspect. This difference is small enough that aspect does not appear to be a controlling factor in fire spread in the Bull Run watershed.

Fire Severity

The severity of historical fire events was studied in three indirect ways. The first two used age class databases that might show the presence of single age classes (implying high severity) or multiple age classes (implying moderate to low severity) at various points on the landscape. The third method was a photo-interpretation of three 19th century fires to evaluate the proportions of low, moderate, and high severity fire on those landscapes.

The Forest Service Ecology Plot database, and the Fire History database generated by this study, were analyzed using the same method: evidence of single or multiple age cohorts on individual plots. The Forest Service Ecology Plots were not established specifically to identify multiple-aged stands, and crews used relatively short, 16-18 inch increment borers primarily to establish tree growth trends and secondarily to determine stand ages. Due to the size of the older age cohorts, borers of these lengths are generally too short to accurately age trees >300 years old in the Bull Run. For example, one stump near Ecology Plot 3018 was 465 years old. If an 18-inch borer had been used to core this tree while it was alive, it would have reached age 400 B.P. (before present), yet the tip would have remained almost 50 cm from the pith of the tree. Using the growth rings at that age

(5.5 yrs/cm) applied to the remaining distance to the pith would have resulted in a tree age estimate of 622 years, almost 160 years off the true tree age. The Ecology Plot data were nevertheless very useful. They were accurate in determining the ages of younger stands (<125 years) and were helpful in identifying stands where two age classes of Douglas-fir might be present, so that they could be subsequently field-checked.

From the Ecology Plot database, samples were stratified by plant series (Table 3). Only two samples were from the *Tsuga mertensiana* zone, because of its limited extent in the watershed, and neither one had multiple age cohorts. In the *Abies amabilis* zone, 4 of the 6 plots had age samples indicating single cohort stands. Two plots had unusual age data and were field checked. As an example, on plot 1417 there were listed a 680-year-old western hemlock and 454-year-old Douglas-fir, an unusual situation because a fire initiating the 454-year-old Douglas-fir generally would kill a 225-year-old western hemlock (after another 454 years, now 680 years old). This stand and two adjacent clearcuts were sampled. No very old western hemlock age class was evident, nor was any char seen on boles. One core and two stumps of Douglas-fir were aged, with stand age estimates from 465 (stump)-493 (core with about 50 years added to estimate) years old. The conclusion is that this is a single age stand. The other unusual Ecology Plot was 3055, where Douglas-fir ages of 739 and 580 were listed. Douglas-fir stumps in the vicinity of this plot were aged at 753 and 755, with no younger cohort of Douglas-fir evident. Subsequent field checks in the vicinity revealed stump ages in the 480-490 range and four additional stumps in the range of 747-748 years old, resulting in this plot being classed as multiple-aged. In summary, for the *Abies amabilis* series, 5 of the 6 plots had single cohort stands, with the vicinity of the sixth plot having some evidence of survival of about 250 year old Douglas-fir (now 750 years old) in a fire about 500 years ago.

Table 3. Number of plots or pixels in single or multiple age classes in the Ecology Plot database (plots), Fire History database (plots), and photo-interpreted fire severity portion (pixels) of the current study. In the photo-interpreted study, low and moderate fire severity classes are combined in the "multiple" category. Figures in parentheses are percents.

Database	*Tsuga heterophylla* series		*Abies amabilis* series		Total	
	Single	Multiple	Single	Multiple	Single	Multiple
FS Ecology	28 (88)	4 (12)	5 (83)	1 (17)	33 (87)	5 (13)
Fire History	101 (78)	30 (22)	46 (74)	16 (26)	147 (76)	46 (24)
Photo-Interp*					1130 (69)	508 (31)

*not differentiated by plant series

The *Tsuga heterophylla* series, which is more widespread in the western lowland portion of the Bull Run, had the most plots and the most evidence of multiple cohort stands. Of the 33 plots evaluated here, the original Ecology Plot data suggested 21 were clearly single-aged, 2 were clearly two-aged, and 9 were in doubt, needing field checking. Of these 9 field-checked plots, 7 were single-cohort stands and 2 (3016, 3048) contained multiple cohorts. The age cohorts for the 33 plots were: 28 single-aged and 4 multiple-aged.

The Fire History database (Table 3) showed slightly higher proportions of multiple-aged stands than the Ecology Plot database. Between 74-78% of the plots in both plant series had single age cohorts, with the remainder almost all in two-aged cohorts. There are a few examples of three aged cohorts, and one "classic" three-aged stand (see + at western edge of watershed in Figure 2) on the north side of the 14 road in the mile or so east of its confluence with the 12 road (Note: the middle-aged cohort, about 250 years, does not appear in the NFR reconstruction because it is of very limited extent in the extreme southwest corner of the watershed). The trend for the Fire History database to have more multi-cohort stands is consistent for both plant series, and may be due to the differences in data collection. The Fire History database typically had more tree ages per plot, with a specific emphasis on attempting to define multiple ages if they were present. Data collection focused on trees likely to be disturbance markers, primarily Douglas-fir. Ages may also have been more accurately determined in the Fire History database because longer (75 cm length) increment borers were used.

Fire severities inferred from Ecology Plot and Fire History databases suggest that 75-90 percent of the stands have a single early seral cohort of Douglas-fir, and that 10-25 percent of the stands have two or more early seral cohorts. In both the *Tsuga heterophylla* and *Abies amabilis* zones, this pattern appears to be about the same, probably because Douglas-fir above ages 100-200, which is the typical post-fire residual tree in both series, has about the same fire resistance in both forest types.

The photo-interpreted fire severity from late 19th century fires suggest that high severity fire is the most common pattern experienced (Table 4): 62-73% of the area appeared to be a single, young canopy age class. Roughly 18-31% of the area had a substantial residual component, and this was most evident on the Falls Creek fire, particularly in its western portion. Only 7-9% of the land area was photo-identified as low severity fire in these three fires. Comparison with the two age class databases (Table 3) indicates that these photo-interpreted fires had a slightly lower high severity component than the age class

Table 4. Proportions of selected Bull Run watershed fires in high (>70%), moderate (20-70%), and low (<20%) fire severity classes, based on residual canopy measured by photo-interpretation.

Fire	Fire Severity Level		
	High	Mod	Low
Camp Creek	73	19	8
Falls Creek	62	31	7
Hickman Butte	73	18	9

databases. This may be due to the age class data collection being biased to the interiors of well-defined patches, so that edge effects were underrepresented in the age class databases.

The classification accuracy for the Camp Creek fire by fire severity category was fairly precise between the three photo-interpreters: low severity, 97%; moderate severity, 93%; high severity, 93% (e.g., the maximum difference between any two observers for the percentage of land area in a fire severity category was 3%, 7%, and 7%). Larger accuracy differences occurred when individual cells were used as a basis of comparison, resulting in 75-80% correspondence for individual pixels of a given category. The Hickman Butte and Falls Creek fires were not cross-checked for accuracy, but based on similar fire severity are probably similar in classification accuracy.

All three of the approaches to evaluate fire severity produced consistent results, although each of the approaches has bias. The Ecology Plots, Fire History Plots, and photo-interpreted fires from the late 1800's indicated that high severity fire was the dominant type of fire affecting the Bull Run watershed. Estimates of high severity fire based on these three data sources ranged from 62-90 percent of the area affected. Moderate severity fire accounted for much of the remaining area (18-31%), with low severity fire accounting for <10 % of the burned areas.

The spatial distribution of low and moderate severity fire suggest it is most common at the edges (150 m, or two tree lengths) of the fires. At the Camp Creek fire, 86% of the low and moderate fire severity occurred within the edge zone. At the Hickman and Falls Creek fires, the percentages of low/moderate fire severity within 150 m of the fire edge were 58% and 52%, respectively. The proportions of low/moderate and high fire severity differed significantly between the fire area as a whole and the 150 m edge zone ($\chi^2 < .005$) for each of the three fires, suggesting that low and moderate severity fire is more common at the edge between high severity fire and unburned forest. However, while moderate to low severity fire is largely an edge phenomenon, it also is found in the interior of the fires in the vicinity of drainages that the fire passes across. Even within areas of high severity fire, occasional residuals can be present, so the conclusion that the Bull Run is primarily a high severity fire regime does not mean residuals are totally absent from the landscape.

Field checks at the Camp Creek Fire suggest that proportions of low severity fire were not misidentified or unidentified by photo-interpretation. The perimeter area of low severity fire based on intensive field searches for surface charcoal was calculated to be 44 ha, about 3% of the high severity fire zone, suggesting that the photo-interpreted proportions are not highly biased against the identification of low severity burn areas. The largest area of lower severity fire was on the southwest edge of the fire. This may be the result of slowly dissipating fire activity from fires pushed by winds from the east or northeast after those winds moderate.

At the conclusion of this study, we received an additional database of tree ages from the Forest Service (N. Diaz, Mt. Hood National Forest, unpublished data). Due to substantial adjustments of Douglas-fir tree ages in this newer database, we did not attempt to incorporate these data into the interpretation of fire severity. If accurate, they do suggest wider ranges of Douglas-fir ages than either the Ecology Plot or Fire History databases, and suggest that the issue of fire severity might be further addressed by incorporating all these databases into future research.

Fire Seasonality

From the 20th century record, there are similar numbers of human-caused and lightning-caused fires (42 human-caused, 31 lightning, and 5 unknown). The largest number of fires (55) are in the Class A size (0-.1 ha), with 7 Class B (0.1-4 ha), 5 Class C (4-40 ha), 5 Class D (40-120 ha) and 6 Class E (120-400 ha). There have been no fires exceeding 500 ha in the record for this century. A total of 1920 ha are known to have burned, although occasional fires early in the record have no size class associated with them. Most of the acreage has burned in the 12 largest fires of record. All have been escaped slash/brush fires except as noted in parentheses. Sizes in descending order of area (ha): 468, 390, 315, 300, 145, 125 (logging), 123, 85, 81, 80, 40 (Campfire), 40. All recorded lightning fires have remained small (almost all Class A, one Class B).

The fires have been confined to summer and autumn months (Figure 9). The big fires (Class B-E) are skewed somewhat to the late summer, probably because slash burns were historically ignited in the autumn. Of the 16 lightning fires that were dated to month and day, 10 occurred in July, with one in June, 3 in August, and 2 in September, so that the mode of the distribution is in mid-summer. Some of these may have smoldered around for weeks before a severe fire weather event (east winds) allowed them to grow to considerable size. Based on these data, a 4-month fire season (July, August, September, October) appears to occur in the Bull Run watershed. The fire cycle model produced results comparable to earlier simulation results found by Agee (1990) for the Wind River, across the Columbia Gorge from Bull Run, although the Bull Run had slightly fewer ignitions. The percent of total ignitions by month were: June, 15%; July, 33%; August, 28%; and September, 24%. This simulation parallels the actual seasonal distribution of lightning fires. As the model does not simulate October, no fires were generated for that month, but lightning and ignition could occur then. With favorable burning conditions known to occur, given the number of debris burn-caused fires in October, this month should also be considered part of the significant fire season.

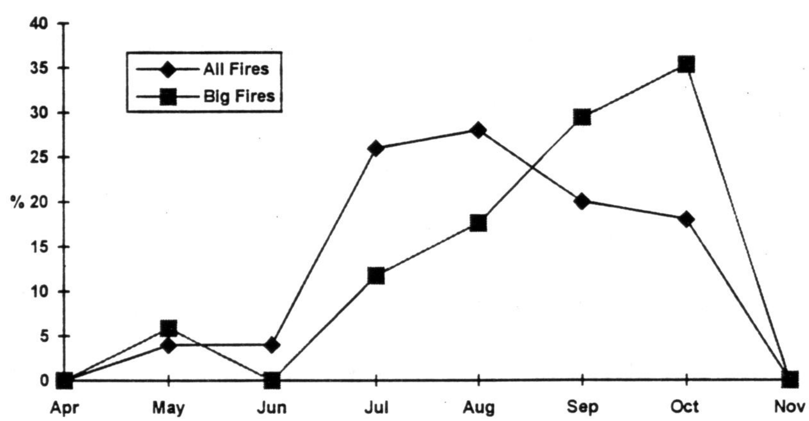

Figure 9. Percentage distribution of wildfires in the Bull Run watershed, 20th century. "Big" fires are those exceeding 0.25 acres in size.

Fire Synergism

Extension of wind into adjacent unburned forest occurs at all edge locations and along all aspects at any given edge. At the intensively studied Camp Creek fire, the southwest and northwest edges of the fire had greater lineal extension of windthrow than the northeast or southeast edges (Figure 10), but all statistical tests were nonsignificant. The variation among transects was great enough that orientation of the slope along the edge of the fire (Table 5) was not associated with significant differences of windthrow penetration. With larger sample sizes, the design would have been more powerful. In any event, the extension of windthrow does appear to be a real phenomenon, although it is relatively localized at the fire edge and small in relation to the size of the large patches created by fire in the Bull Run.

The synergism between wind and fire produces unique stand structures. At least four sites were found where historical windthrow was apparently followed by a patchy burn some years later, allowing shade-intolerant Douglas-fir to establish amidst a canopy of Pacific silver fir and/or western hemlock. The true fir and hemlock were released by the windthrow and missed by the patchy fire. Conversely, wind has also followed fire as a disturbance on the landscape, sometimes producing relatively dense understories of shade-tolerant trees with a scattered emergent canopy of the shade-intolerant Douglas-fir. None of these sites was quantitatively measured.

Other interactions between fire and landscape disturbances include: fire/disease and fire/insects. Either disturbance factor may precede the other (Agee and Edmonds 1992). When fire injures a tree, either insects or disease organisms are likely to invade. Trees killed by pathogens or insects will at least temporarily increase fire hazards. Due to the

Table 5. Distance of windthrow from edge of high severity fire into unburned forest by aspect. A northeast-facing aspect, for example, could occur at any orientation edge of the fire (northeast, southeast, southwest, or northwest), as it refers to the aspect at a given edge of the fire.

Aspect	Distance of Low Severity Fire	Total Distance of Windthrow
	meters	
Northeast 20°-120°	80	120
Southwest 200°-300°	123	212
Northwest/Southeast 120°-200°/300°-20°	173	238

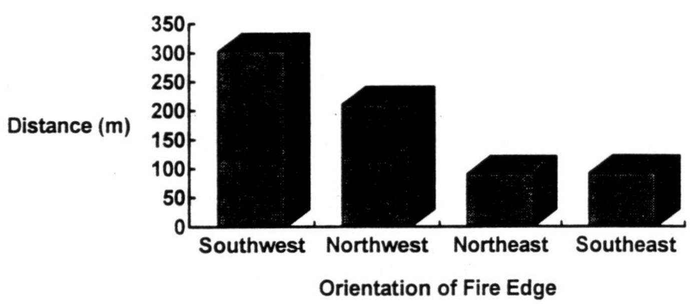

Figure 10. Expansion of fire edge by subsequent windthrow, as determined by distance of tip-up mounds beyond edge of high severity fire zone. Aspect refers to the edge of the fire, not the edge of the unburned forest (which would be 180° different).

difficulty of reconstructing past insect and disease events, it is not possible to estimate the degree to which the synergism with fire is important. It must be significant around the edges of stand replacement events and in patches of moderate to low severity fire, similar to the effects of wind, but is often species-specific (such as Douglas-fir beetle [*Dendroctonus pseudotsugae*] on Douglas-fir).

Discussion

The fire regime of the Bull Run watershed appears to have a high severity fire regime characterized by infrequent fires of generally high intensity that are largely stand replacement events. As the events are identified from interpretation of age classes, several closely-spaced fires could be interpreted as one fire. From the standpoint of current issues, whether each identified event is one fire, or perhaps more than one fire clustered at nearly the same time, is probably not of paramount importance.

The overall natural fire rotation for the Bull Run (350 years) is quite long, although shorter than the 465 year NFR calculated for the Mount Rainier area (Hemstrom and Franklin 1982). The Mount Rainier forests are primarily in the *Abies amabilis* zone, in contrast to the predominantly *Tsuga heterophylla* forest zone of the Bull Run. The periods of large fire events corresponds to similar periods identified elsewhere in the western Oregon and Washington area as times of large fires (Figure 11; Stuiver and Quay 1980, Agee 1993). These periods are times of sunspot minima which apparently are associated with periods of lower than normal solar activity. These global cooling periods may be linked to changes in the factors associated with large fire events in more recent times in the wetter portions of the Pacific Northwest: drought, lightning activity, or the occurrence of east winds. We do not understand these linkages well. Forest fire in the Bull Run appears to be a good example of "punctuated disequilibrium", where ecosystems in "normal" times do not exhibit much fire activity, and although the "abnormal" times may be widely separated in time and perhaps of short duration, they have major impacts on the forests we see today. The vast majority of forests in the Bull Run have been produced by a handful of past fires that range back to 750 years ago, and the current species composition and structure are still very much influenced by the trees that established after these events of antiquity.

Across the Pacific Northwest, the *Abies amabilis* zone, as a cooler, moister forest type, has longer fire return intervals than the *Tsuga heterophylla* zone (Agee 1993). Yet in the Bull Run, the *Abies amabilis* zone has a shorter natural fire rotation. This pattern appears to be linked to the spatial distribution of the higher elevation, *Abies amabilis* forests around the rim of the watershed, which appears to be susceptible to incursion of fires from drier, low elevation areas on the surrounding landscape. In the large fire

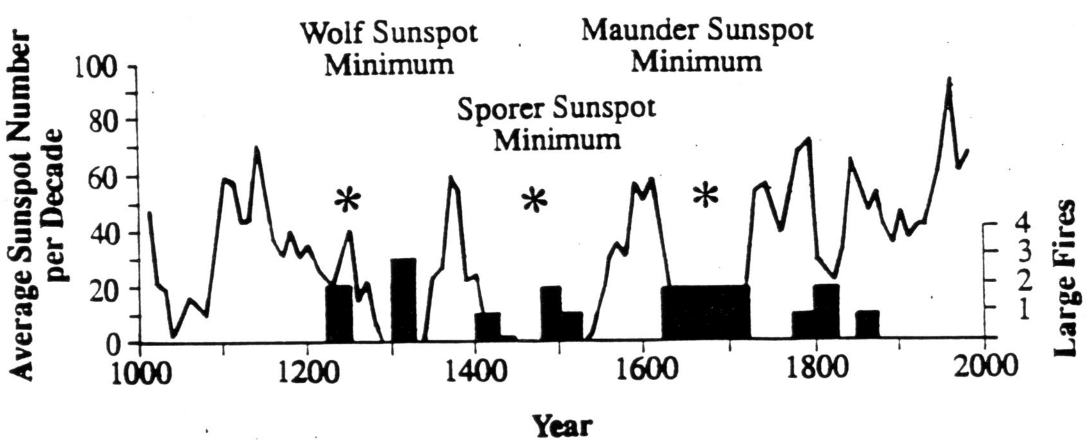

Figure 11. Large fires of the western Cascades and Coast Range appear to concentrate during periods of sunspot minima (from Agee 1993). The three earliest periods of fire activity in the Bull Run are shown (see large asterisks) for comparison and seem to fit the same pattern.

events, much of the watershed has burned, regardless of forest type. But in many of the smaller events, fires appear to have concentrated in the rim environments where Pacific silver fir forests are more common. One possible explanation is that lightning has been more common in these rim areas, and the subsequent fires have been extinguished by later storms as they burned down into the watershed. Another possible explanation is that these fires are entering the watershed from other areas. When the seasonality of fire activity is considered, this seems the more likely explanation. The fire season tends to concentrate in late summer, and as in other regional areas, large fires tend to be associated with east winds (Cramer 1957). Low humidity and sometimes high velocity winds are associated with east winds (more generally called foehn winds). September and October are the dry season months with the highest frequency of east winds. Fires beginning somewhere in the arc from northeast to southeast of the watershed may have burned up to and into the watershed. The 1873 event around Hickman Butte is shown on early USGS maps (Figure 3) as encompassing a broad area to the east. This type of fire is much more likely to be widespread under east wind conditions that under the usual, more moist westerly flow. The east winds in the Bull Run area occur more frequently in exposed places between 250-1000 m elevation than at lower elevations (Cramer 1957), which might help to explain why fires entering the Bull Run tend to dissipate once they have entered the watershed.

The watershed appears to be influenced by fires originating from outside, with less fire activity generated from fires starting in the watershed. However, not all fires appear to have entered the watershed from outside. The Camp Creek fire (1870's), for example, appears to have been contained largely within the watershed. It has a cigar-shaped southerly portion which appears to be consistent with a wind-driven spread. However, it is possible that this fire is the northern extension of a much larger fire that came from the south (Figure 3), so that conclusions about fire origin from investigation of fire shape have to be cautiously interpreted.

When fires occur in the Bull Run, they tend to be stand replacement events of high severity. The three independent sources of data analyzed (age classes and photographs) consistently identified the major fire severity class as "high"; nevertheless, some residuals can be found within high severity portions of past fires. Moderate and low severity burning that leave significant residual tree canopy occurred primarily around the margins of the burns, and in riparian zones within the burn. The recent age class data obtained from the Forest Service suggest a more uneven-aged structure of stands in the Bull Run, although as mentioned earlier these data did involve a lot of tree age adjustment. We feel relatively confident that the primary type of fire is from high severity fire events, but further research would be helpful more precisely determine the distribution of fire severity levels in the watershed. Clearly, our interpretation for the Bull Run is not applicable to watershed just a few km north or south, because those areas are much drier and a moderate severity fire regime is much more likely there.

The fire regime of the Bull Run differs from those further to the south, in the H.J. Andrews Forest area (Morrison and Swanson 1992). In the Bull Run, patches tend to burn severely, patch size tends to be larger, and fire return intervals is longer. This contrast appears to be true for the area and immediately to the north in the Columbia Gorge, where moderate severity fire regimes are more common. The 1991 Falls fire near Multnomah Falls, several km north of the Bull Run watershed, show a classic moderate severity fire pattern, with low intensity underburning, fires that thinned out the smaller trees only, and some stand replacement patches. Why is the Bull Run more similar in fire regime to the wetter forests found, for example, at Mount Rainier and in the Olympic Mountains? The answer may be found largely in the precipitation regime: it is a very wet area compared to areas due north and south (Figure 12A and 12B). The Bull Run is situated such that the major storm tracks drop at least twice as much precipitation there as in the Columbia Gorge directly to the north or in portions of the Clackamas River drainage directly to the south of the Bull Run. The regional map (Figure 12A) shows the Bull Run receiving over 330 cm (130 in) of annual precipitation, but more local data in the watershed (Figure 12B) indicate that the higher elevation areas receive over 430 cm (170 in). This added precipitation can affect the moisture content of dead fuels and live foliar moisture, too, well into, if not through, the dry season, often enough to extinguish fires that may enter these areas. It is not surprising that the two oldest patches of forest (see + on Figure 12B) are in the wettest portion of the watershed.

In this generally high severity fire regime, there are residual trees left on the landscape after most fires. They tend to be clustered around the edge of the fires, and with the assumption that these are largely east wind driven fires, at the western edges of the fires as they were extinguished naturally when the east winds dissipated. One area where this effect is especially apparent is along the 14 road east of its confluence with the 12 road. Three age classes of Douglas-fir (≈500, 250, and 115 years B.P.) coexist representing a likely stand replacement fire in the 1493 event, and less severe burning in the 250 and 115 year events.

The synergistic effects of fire were only partially investigated, primarily in the fire-wind interactions. This interaction tends to be localized at the fire edge, primarily because the fire interiors tend to have few residuals. Wind may help to create more heterogeneous post-fire structures near the fire edges, although the areal extent of the effect is relatively limited. Other interactions of fire with insects or disease were not investigated.

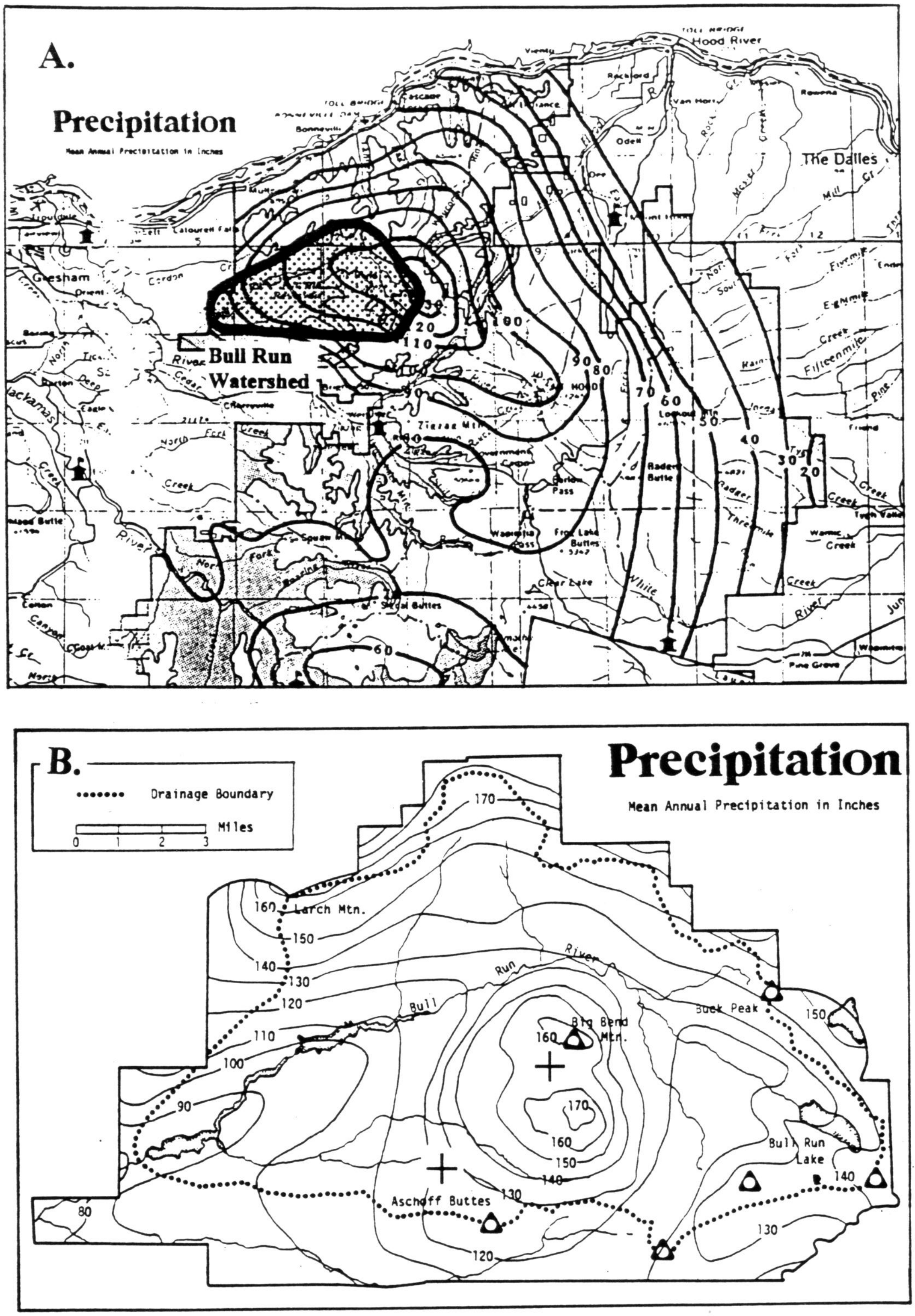

Figure 12. Precipitation (inches) on the Mt. Hood National Forest with the Bull Run shown as a stippled pattern. The Bull Run is wholly within the wettest zone, excellent for water production and making fire less probable.

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