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CHRISTMAS STORM DAMAGE ON THE H. J. ANDREWS EXPERIMENTAL FOREST

by

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The storm preceding Christmas, 1964, brought flood damage of major proportions to watersheds in the Douglas-fir zone of western Oregon. The H. J. Andrews Experimental Forest (Berntsen and Rothacher, 1959), located in the upper McKenzie River drainage about 50 miles east of Eugene, Oreg., is typical of upstream areas damaged by the storm. Twelve years of precipitation and runoff records at this site enable us to evaluate this storm. In this case history, we have attempted to show, at least in part, why this storm caused such extensive damage.

THE STORM

The meteorological explanation of the weather conditions causing this flood was summarized in the Portland Oregonian in the Sunday edition of January 2, 1965. This storm was preceded by a period of below-freezing temperatures. A warm front from the Pacific Ocean, overriding an artic airmass, brought the snowline down to near sea level. Snowfall changed to continuous rain, beginning about midnight Sunday, December 20, as air temperature began a rising trend. The result was an extreme example of a rain-on-snow storm in which melt water from a moderate snowpack was added to rainfall runoff when the air temperature warmed from freezing to the mid-50's F. Streamflow resulting from this storm exceeded measured maximum peaks for 50 years' standing and set new records at a number of locations throughout Oregon. This rampaging flood surge caused widespread erosion in stream channels and destroyed roads, bridges, and personal property valued in the millions of dollars.

This storm was one of the most severe of six that have occurred in the Willamette Valley in the last 104 years. It is not known how severe erosion and sedimentation was during earlier flood-producing storms because logging in watersheds of headwater streams had not yet begun and access was only by trail.

On the experimental forest, fresh snow began falling on a moderate snowpack on December 18 as temperatures gradually warmed to near melting (fig. 1). By the morning of December 20, after 1.3 inches of water had fallen as snow, temperatures continued to rise, and snow changed to mixed rain and snow. Streams began to rise on Monday morning, December 21, as rainfall intensity increased. An abrupt temperature rise at noon the same day (fig. 1), followed by maximum rainfall intensities near midnight, brought streams to the highest flow measured in 12 years of record.

This peak flow was the result of 8.25 inches of rain in more than 2 days plus an undetermined amount of snowmelt water. Of 1.5 feet of snow at 1,500-foot elevation on the morning of December 21, only scattered patches remained on the morning of December 22. Unfortunately, we have no measure of water content of this snow but estimate that it contained an equivalent of 3 or 4 inches of water. Rain plus snowmelt water, totaling more than a foot, was released on the land surface while streams in the three experimental watersheds reached peak flows.

THE EXPERIMENTAL WATERSHEDS

The watersheds in the H. J. Andrews Experimental Forest are typical examples of headwater areas sustaining extensive damage during the storm. They have deep soils, developed from tuffs and breccias, which contain a high percentage of silt and clay. Overland flow has not been observed on these watersheds even at the time of peak flows. This is probably the result of extremely porous soils together with moderate precipitation intensities characteristic of this climate. Mean annual temperature is about 48° F. at 1,600 feet. At this elevation there is seldom a continuous winter snowpack. Annual rainfall averages 92 inches, but 95 percent of this water falls during the cool season from September to May.

Although the watersheds vary in size from 149 to 250 acres, they are similar topographically. They face to the northwest (fig. 2). Maximum side slopes on each range from 85 to 105 percent and the average gradient of the stream channels from 28 to 35 percent.

For 7 years after watershed studies began, the old-growth Douglas-fir canopy in the experimental watersheds remained unbroken. During 1959, 1.6 miles of roads were completed in watershed 3 (Berntsen and Rothacher, 1959), and a fourth of the area was logged and burned in 1962. About 75 percent of the timber in watershed 1 has been harvested by skyline crane since logging began in 1961. Watershed 2 remains in a natural condition as the control watershed.

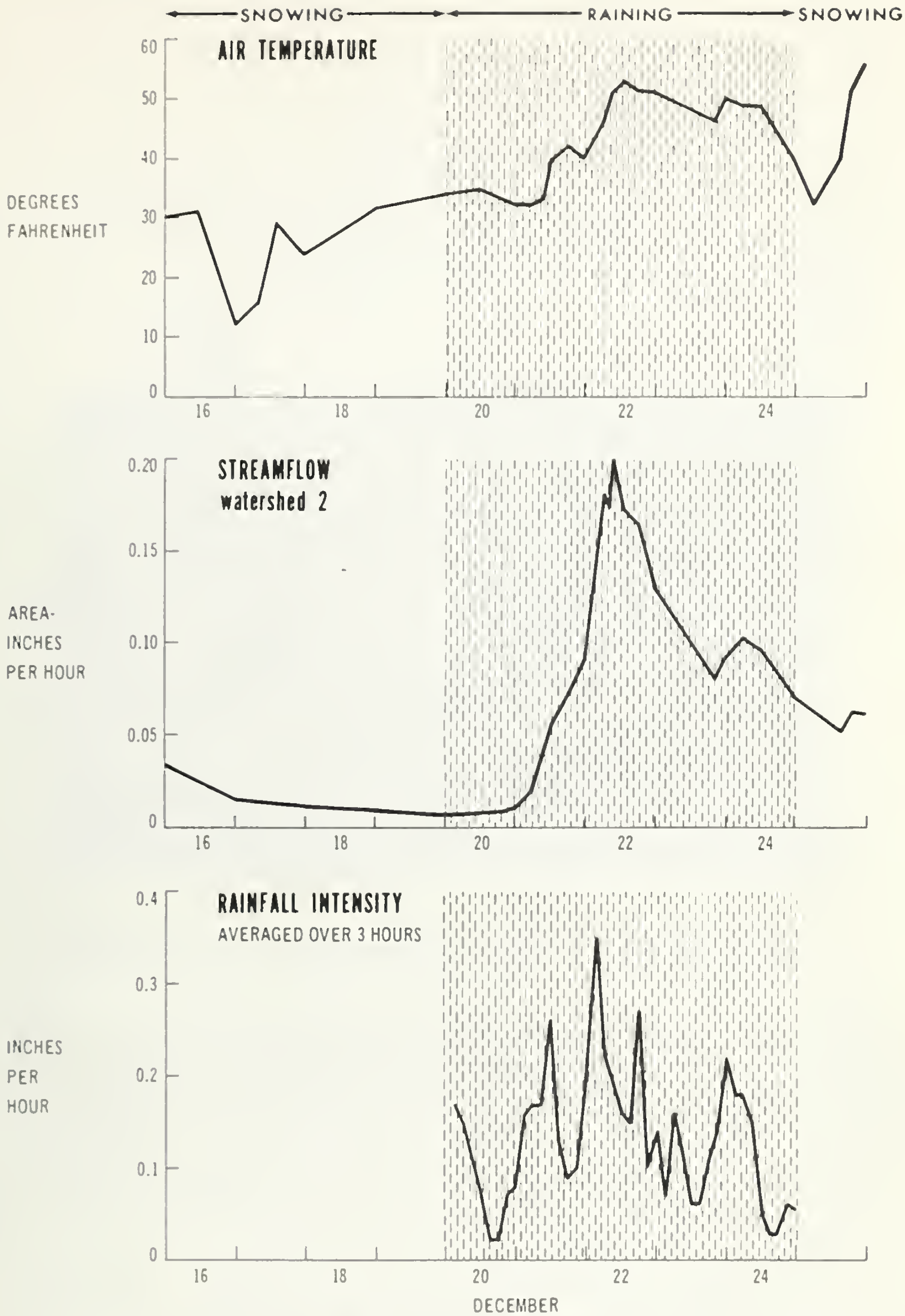

Figure 1.--Weather conditions during the 1964 Christmas storm and streamflow from watershed 2.

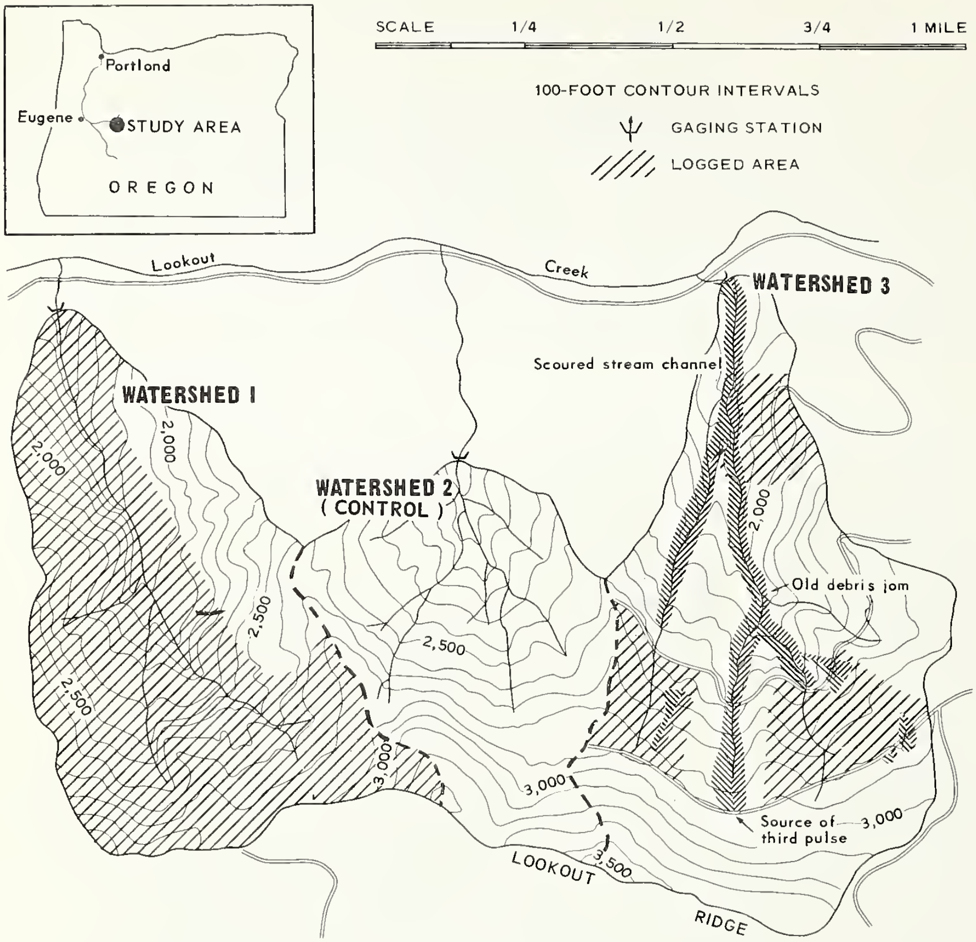

Figure 2.--Experimental watersheds, H.J. Andrews Experimental Forest.

EFFECT OF THE STORM ON THE EXPERIMENTAL WATERSHEDS

The beginning of this storm was not very different from many of the past storms we have recorded on the experimental watersheds. Air temperature hovering near freezing prevented rapid melting of the heavy wet snowpack. Watersheds 1 and 2 carried clear water, but a muddy stream in watershed 3 showed that some erosion had begun.

We were impressed by the severity of the situation about midnight of December 21 when rainfall intensities reached 0.47 inch per hour and air temperatures had warmed 10° to 12° (fig. 1). The streamflow hydrograph at watershed 2 began to rise very rapidly in response to the rain and melting snow. Streamflow in watersheds 1 and 2 reached a peak of 0.26 and 0.20 area-inch per hour by midmorning of December 22. Rainfall, which averaged 0.28 inch per hour for the 6-hour period previous to the storm peak, was only slightly greater than the rate of outflow from watershed 1.

When we inspected the gaging stations at 2 a.m. on December 22, the watershed 3 gaging station had been destroyed by a large debris slide. There were three distinct slide pulses from this watershed. The first, already mentioned, contained mainly rotten logs. The second, a larger pulse of logs and trees, struck the existing debris jam about 8 a.m., December 22. According to eyewitnesses, who narrowly escaped this pulse, about half the debris lodged behind the road fill while the other half was carried over the top of the fill and into the main stream below. Figure 3 shows the debris jam as it then appeared. The largest quantity of debris--mainly gravel and boulders--lodged behind the debris jam during the night of December 22-23 from the third pulse, which filled in the stream channel behind the road fill with about 27,500 yards of this material.

Figure 3.--Debris from watershed 3 as it appeared on December 22, 1964.

Erosion source areas in watershed 3 are indicated on figure 2. Stream channels through which the slide pulses moved were probably the main source of wood debris. Although part of the main channel had been scoured[1/] by a previous slide in 1961 (Fredriksen 1963), one large debris jam remained from this slide. The first two slide pulses

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[1/] Since slides generally scour stream channels to bedrock, this phenomenon is frequently referred to as channel scour.

carried material from this debris jam plus debris accumulated in the channels. The third pulse originated from a timbered area which was recognized as an unstable area in the summer of 1964. Numerous other small failures were noted (fig. 2), but their contribution to the total load of eroded material moved by the storm was small.

Watershed 1 and 2 streams, by contrast, carried little sediment. Though the total storm sediment load coming from watershed 2 (control) was small by comparison with events in watershed 3, the total load was larger than has been measured during the past 8 years. Several yards of gravel passed through the flume near the storm peak--probably from streambank cutting--but no evidence of mass soil movement was noted during several inspection trips. No evidence of accelerated erosion was noted in watershed 1. Although peak runoff was only slightly less than the rate of applied rainfall, the water would have met drinking water standards except for very short periods during the storm.

Behavior of the experimental watersheds during the storm was fairly typical of other watersheds in the vicinity. A hasty check of headwater stream channels showed that 10 out of 20 were severely scoured by debris movement in the channel, similar to that observed in watershed 3.

WHAT MADE THIS STORM DIFFERENT?

The 1964 Christmas storm was one of the most destructive witnessed in 100 years of recorded history in western Oregon. It would be of interest to compare this storm with other storms which have occurred during past years. We will compare peak streamflows and precipitation amounts causing the peak. This is a technique frequently used to compare storms. Also we will discuss the erosion potential of frozen soil since forest soils along the Cascade front were subjected to subfreezing temperatures for several days before the storm.

Precipitation vs. Runoff

Peak streamflows in watershed 2 are compared with the maximum 6-hour precipitation falling before the peak (fig. 4). This watershed was selected for the comparison because vegetation cover has remained undisturbed during the past 12 years. Lines are drawn at 100, 80, and 60 percent of the rate of applied rainfall so that storms of different size can be compared. The 1964 Christmas storm reached flow rates greater than have been measured before but at smaller 6-hour amounts than have been measured during previous storms. Apparently snowmelt water made up the difference. The storm of December 19, 1961, was the only other storm which caused runoff rates greater than 60 percent of potential runoff. This event, also a rainfall-snowmelt storm, caused many examples of channel scour and mass movements in the vicinity and scoured the channel in watershed 3 (Fredriksen 1963).

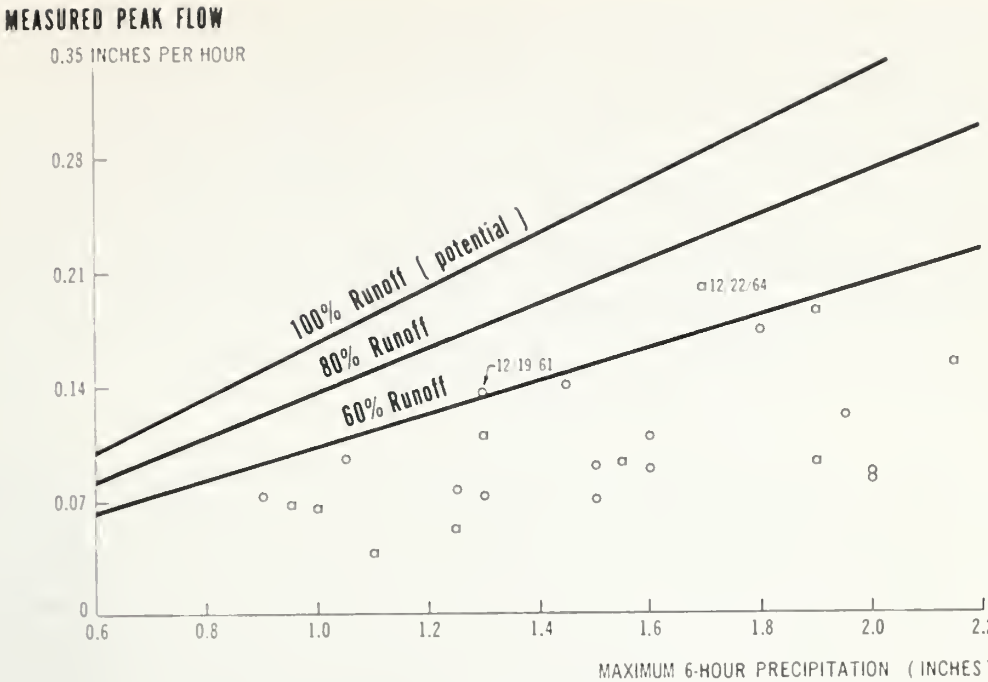

Figure 4.--Peak flows compared with maximum 6-hour rainfall, watershed 2.

Storm Size

Because rainfall from the Christmas storm lasted about 4 days, other 4-day storms measured in the experimental forest were grouped into size classes (fig. 5). Of 44 storms measured during 12 years,

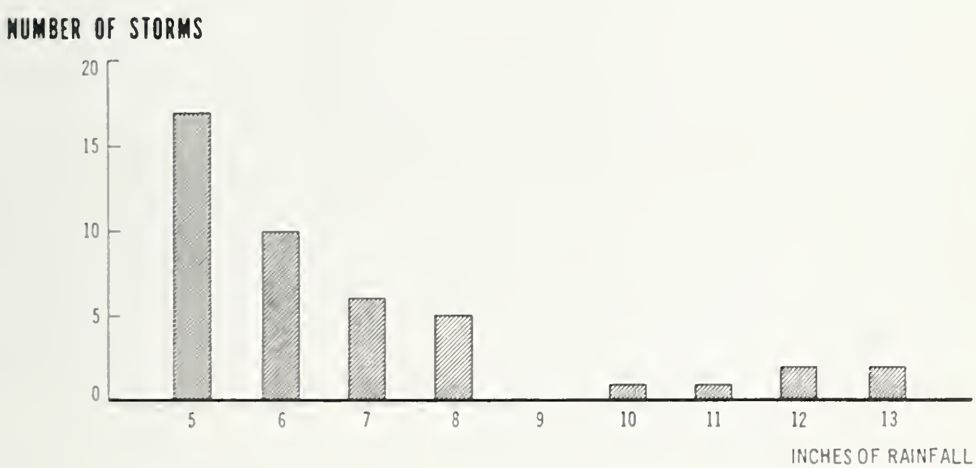

Figure 5.--Frequency of 4-day storms by size class, 1952-64.

6 delivered more than 10 inches; 2, including the Christmas storm, measured more than 13 inches. Considering the short span of records at the experimental forest, we believe 4-day storms which deliver 13 inches are probably not unusual.

Miller (1964) classifies 4-day storms totaling between 10 and 12.5 inches, along the Cascade front in Oregon, as events with a 100-year return period. Since six 4-day storms larger than 10 inches have been measured in the experimental forest in 12 years, the size of storms with a 100-year return period may be larger than present information would suggest.

Frozen Soil

Though we currently have no studies of soil freezing at the experimental forest, published evidence indicates the hydrologic potential of soil freezing. Freezing has been suggested as a cause of accelerated erosion where ice near the soil surface prevents the infiltration of water. During one winter, Hale (1950) found no frost in soils supporting Douglas-fir stands along the Cascade front even when the protective influence of vegetation cover had been removed by logging. Striffler (1959) in the central United States also found little or no concrete frost, which restricts the internal drainage of soils, in highly aggregated forest soils similar to soils under Douglas-fir stands. However, frozen soil has been observed at the H. J. Andrews Experimental Forest during snow-free winter periods of sustained below-freezing temperature. Though the soil is frozen, spaces between the soil granules remain free of ice and the soil retains the ability to conduct water. So frozen soil probably did not prevent passage of water into the soil mantle along the western slope of the Cascade Range.

EROSION RESULTING FROM THIS STORM

Erosion Sequence on Headwater Streams

Thornbury (1954) describes erosion under humid maritime climate typical of the north Pacific coast. Rapid down-cutting by streams and valley extension by headward erosion are typical of this region. Erosion from the head of the drainage in watershed 3 during the Christmas storm occurred as mass movements. Though we did not witness this headwall failure, we deduce from circumstantial evidence that this channel scour slide resulted from several related events. The slide was triggered when unconsolidated soil material collapsed into the channel. The high-velocity stream, temporarily dammed by the slide, soon saturated the already wet slide material, and the entire mass moved down the channel taking with it all debris in its path.

Wood debris in these drainages, such as fallen trees and logging debris, adds bulk to the moving mass--thereby scouring a larger area of these deeply incised channels. Tree-length logs snatched from creek banks carry more soil material into the drainage and disturb more area along the stream margins. Road fills and bridges, where roads cross the stream, can seldom withstand the impact of the moving debris. Consequently, the mass of these structures is frequently added to the bulk of material moving down the drainage. Rothacher (1959) has aptly discussed the debris problem in small drainages.

We witnessed the end of a slide which occurred in another watershed in a nearby logging unit. Upon hearing low rumbling sounds and earth tremors, we rushed to the scene only in time to witness the last one-third of the slide travel. The slide moved very rapidly and as a single mass through nearly one-quarter mile of channel in less than a minute.

Erosion Sequence in Lower Gradient Streams

Mud and debris flows in headwater streams contribute to erosion in lower gradient channels. Floating wood debris from source watersheds, together with old debris already in the channel, move downstream until an obstruction is encountered. Debris jams, which form behind these obstructions, are collecting points for streambed gravels and boulders. As the stream channel is plugged, the water level behind the debris jam rises and eventually finds a new channel. Rock and soil material, removed when the new channel is cut, adds to the streambed material already in motion down the stream. Channel cutting undermines the roots of trees adjacent to the channel. Trees falling across the channel serve as natural barriers for the formation of new debris jams. So, in addition to the force of water moving down the channel, debris greatly accelerates the rate of channel erosion. Damage or total destruction of roads and bridges adjacent to or crossing these low-gradient channels was the result of channel cutting, sometimes by water alone but more frequently by debris together with the flood runoff. As use of forest land in mountainous terrain becomes more intensive, damage to forest improvements from these widely spaced storms can be expected to become more severe.

MAGNITUDE OF EROSION DURING THIS STORM

In Experimental Watersheds

The magnitude of erosion and resulting sedimentation during the Christmas storm can be evaluated by comparison with 9 years of sedimentation records from the three experimental watersheds. Suspended sediment carried annually from these watersheds with winter storms has ranged from 0.006 to 0.120 ton per acre and the heavier streambed material from 0.3 to 2.4 cubic feet per acre. The annual sediment load is related to the number and size of storms occurring during a winter. When snowmelt water is added to rainfall during these long-duration storms, erosion is greatly increased by mass movements. One slide in December 1961 carried 10 cubic feet per acre of streambed gravels and 1.1 tons per acre of suspended sediment through the watershed 3 channel. Erosion in watershed 3 during the Christmas storm deposited about 3,000 cubic feet per acre of gravel, rock, and logs in the stream channel--300 times the amount measured during the 1961 slide. Minor importance of sedimentation in the other two watersheds shows that erosion rate is extremely variable, even in adjacent watersheds which are topographically very similar. Though there were no slides in watershed 1 during the Christmas storm, late in January 1965 another storm, nearly as large, caused a slide which deposited several tons of material in the stream channel. As was pointed out previously, the number of channel scour events in other headwater streams in the experimental forest were about in the same proportion to these observed on the experimental watersheds.

In Lower Gradient Channels

Lower gradient channels carried very large quantities of solid material during the storm. Though we lack quantitative data, from evidence of channel erosion along the main channel and sediment contributed from mass movements in headwater streams, we conclude that the total sediment load was many times the load observed during past storms. The deafening sound of boulders grinding together as they moved down the streambed was evidence of the magnitude of erosion taking place.

SUMMARY

Erosion during the 1964 Christmas storm was the result of a combination of climatic circumstances which has occurred in the past and undoubtedly will occur again. Six major flood-producing storms have occurred in the Willamette Valley since 1861--an average of one every 17 years. Of these, the Christmas storm was probably one of the largest.

Sedimentation in significant quantities along the west slope of the Cascade Range occurs as a result of runoff from prolonged low-intensity rain together with snowmelt water. The Christmas storm was of this type. Sedimentation began in high-gradient headwater streams. Large quantities of soil, rock, and wood debris moved into lower gradient channels collecting runoff from headwater streams. Moving debris in lower gradient channels was responsible for accelerated channel erosion and damage or destruction of forest roads and bridges.

Rainfall amounts reaching 12 to 13 inches in 4 days cause moderate local erosion and sedimentation, but when snowmelt water is added to this overabundant rainfall, damage is severe. Frequency of 4-day rainfall amounts this large is greater than regional rainfall records would indicate.

We can expect that erosion and sedimentation will be more severe in future years as the density of forest transportation structures is increased to provide access to timber stands not yet under sustained yield management.

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