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Geological Survey

Potential effects of future volcanic eruptions in Mount Rainier National Park, Washington

By

Dwight R. Crandell

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Introduction

An evaluation of the geologic events of the last 10,000 years at Mount Rainier suggests that, if the past pattern of volcanic activity continues, a substantial steam, pumice, or lava eruption will occur on an average of once each 500-1,000 years. Furthermore, these eruptions predictably will be accompanied by destructive floods and mudflows along the floors of some valleys that head on the sides of the volcano. The purpose of this report is to describe ways in which an impending eruption might be recognized, to discuss the effects that might be anticipated from an eruption, and to recommend ways in which potential threats to human life might be reduced or eliminated. In addition, the potential hazards at various visitor-use facilities and Park maintenance installations are discussed, and suggestions are made concerning the possible relocation of some of these facilities. The accompanying Appendix, "Procedures to follow in case of a volcanic eruption," is prepared in such a way that, if desired, it can be reproduced for distribution to Park Service personnel responsible for the various installations in the Park.

The information given here concerning the eruptions of the last 10,000 years is summarized from Geological Survey Bulletin 1238, "Volcanic hazards at Mount Rainier, Washington," by Dwight R. Crandell and Donal R. Mullineaux, which is now in press.

Kinds and frequency of recent eruptions

Since the end of the last major glaciation, about 10,000 years ago, molten rock has been erupted from Mount Rainier at least 10 times. Products of these eruptions include lava flows, pumice,1/ and hot avalanches

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1/ Some geologic terms used in the following discussion are pumice, ash, lapilli, bomb, and pyroclastic. Pumice consists of frothy or cellular volcanic glass in which the included air space, in the form of bubbles, greatly reduces the weight of the rock. In the Park, pumice from Mount Rainier ranges in size from tiny fragments to blocks nearly a foot in diameter. Ash is a term that refers to air-laid particles of volcanic material less than 4 mm in diameter. Fragments 4 to 32 mm (about 3/16-1¼ in.) in size are called lapilli. Ash and lapilli can consist of glass which may be cellular or dense, pieces of dense rock, mineral crystals, or two or more of these materials combined. The term volcanic ash refers to any fine-grained air-laid volcanic material without regard for its composition. A bomb is a mass of molten rock, explosively thrown from a volcano, that cools and solidifies into a characteristic rounded form before striking the ground. Bombs recognized at Mount Rainier range in size from about 6 inches to 10 feet in diameter. The term pyroclastic refers to deposits of rock fragments or pumice that have been explosively erupted from a volcano and thrown into the air, or to the type of eruption that produces such deposits.

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of rock debris and volcanic bombs. In addition, steam explosions repeatedly have caused rockfalls and rockslides from the summit and upper flanks of the volcano, some of which became thick mudflows when they reached the valley floors. If the future activity of the volcano is similar to that of the last 10,000 years, an eruption of molten rock might be expected on an average of once each 1,000 years, and a large-scale steam explosion accompanied by major landslides probably will occur at least as often. Small steam explosions probably have occurred every few years, and probably will continue at the same rate in the future.

The only eruption of lava within the last 10,000 years built the small summit cone of the volcano. The cone is indented by two craters that are nearly filled with ice and snow. There are still fumaroles along the edges of the craters, and areas of warm to hot rock are present both on the crater walls and on the outer slopes of the cone.

Substantial amounts of pumice have been erupted six times by Mount Rainier within the last 10,000 years, most recently between 2,000 and 2,300 years ago. Pumice deposits from Mount Rainier are mostly restricted to the eastern half of the Park, as shown on figures 1-4. Three additional pumice deposits blanket almost the entire Park; two originated at Mount St. Helens volcano, which is about 50 miles to the southwest, and one came from Crater Lake, Oregon, 250 miles directly south of Mount Rainier. Many other thin and discontinuous beds of sand-sized material between the recognizable pumice layers may be pyroclastic deposits from both Mount Rainier and neighboring volcanoes.

An eruption of molten rock that was accompanied by the ejection of bombs caused a hot avalanche of rock fragments on the east side of the volcano some time prior to 5,000 years ago, and a similar avalanche descended the west side about 2,300 years ago. These hot avalanches of rock debris reached distances in the valleys of the White River and South Puyallup River, respectively, of 7 and 8 miles from the summit of the volcano.

Certain deposits at the volcano are believed to have been formed as a result of steam explosions, probably not accompanied by the eruption of molten rock. One such deposit is a layer of rock debris as much as 3 feet thick northeast of the volcano, which may have resulted from a steam explosion between 5,000 and 6,600 years ago. Other steam explosions probably caused avalanches of rock and clay at least 7 times from the volcano, each of which formed a very large mudflow in the valleys. Such a mudflow about 5,000 years ago moved downvalley for about 45 miles, then spread into the Puget Sound lowland and covered an area of about 65 square miles to depths as great as 75 feet. About 500 years ago, another mudflow originating at the volcano moved downvalley to the lowland, where it covered at least 13 square miles to depths as great as 25 feet. Parts of the areas inundated by both mudflows are now densely populated.

Within historic time, according to a recent compilation by C. A. Hopson, A. C. Waters, V. R. Bender, and Meyer Rubin, eruptions of Mount Rainier were reported on at least 14 occasions between 1820 and 1894, but apparently none resulted in the formation of recognizable pumice or lava. Some, perhaps most, of these "eruptions" may have been dust clouds caused by rockfalls on the volcano; others may have been authentic eruptions, although on a very small scale.

A small steam explosion high on the south flank of the volcano in August 1961 caused a small rockfall, and it was followed by the emission of steam from a vent in the rockfall scar for at least a month and a half. A similar explosion may have triggered a series of very large rockfalls and avalanches from Little Tahoma Peak on the northeast side of the volcano in December 1963 which are described in Geological Survey Bulletin 1221-A. Even more recently, a short-lived steam vent was reported by a climbing party at an altitude of about 11,500 feet on the south side of the volcano in March 1965.

The significance of recent sporadic steam phenomena is not known. These phenomena may be substantially more frequent than the known record indicates, both within the last few years and during all of historic time. On the other hand, the phenomena of the last 5 or 6 years could represent a significant change in the thermal state of the volcano.

Recognition of impending eruptions

An impending eruption might be revealed in a number of ways; some preliminary phenomena would be noticed by people in the Park, but others, such as very slight earthquakes and a change in the thermal state of the volcano, might be detected only by the use of sensitive instruments. Still other ways of anticipating eruptions by instruments are by recognizing changes in the magnetic field at the volcano, and by detecting a slight swelling of the central part of the cone as molten rock rises into it. Also, temperature of fumaroles might increase just before an eruption, and the amount of sulfur and chlorine might increase in fumarolic gases. Alexander R. McBirney (Director of the Center for Volcanology, University of Oregon) has recently pointed out that a study of such changes may be of great value for predicting eruptions at some volcanoes, but nearly useless at others, and that the value of any study can only be established by accumulating and studying data for many years. These studies are best suited to a volcano which erupts frequently, for there it can be determined which phenomena reliably forecast an eruption.

Visual and auditory phenomena

The signs of an impending eruption that would be most readily apparent are clouds of steam, dust, and "smoke" rising above the volcano, although such clouds might indicate that the initial phase of the eruption had already begun. Loud explosions and rumbling noises might be heard, although any single loud noise might easily be mistaken by observers for thunder or a sonic "boom" caused by supersonic aircraft. Other phenomena that might precede an eruption are: (1) appearance of steam jets, (2) increase in fumarolic activity, and (3) abnormal glacier melting at hot spots on the volcano, appearance of melt pits in glaciers, increased melting of snow and ice at the summit cone, and a large increase in stream flow unrelated to weather conditions.

No single phenomenon would necessarily indicate that a catastrophic eruption was about to occur. However, the nearly simultaneous occurrence of several of these phenomena should be regarded with alarm, and should alert personnel in the Park to watch the volcano very carefully and prepare to evacuate the valley floors within and near the Park.

Earthquakes

Numerous earthquakes are recorded in the vicinity of Mount Rainier, but a few are strong enough to be felt, and virtually nothing is now being done to analyze the total record of activity in the region of the volcano. The U.S. Coast and Geodetic Survey has been reporting only about one felt quake per year in the central part of the Cascade Range near Mount Rainier. However, Norman Rasmussen, University of Washington seismologist, reports that the permanent seismographs at Longmire record as many as 4 or 5 small tremors each day.

Rasmussen believes that at least two kinds of small shocks can be recognized from the Longmire records. Some probably result from seismic events that occur at a very shallow depth under or very near the volcano. Most, however, apparently result from deeper events whose direction and distance from the Longmire station are not well defined, but since they also seem to originate at about the distance of Mount Rainier, they conceivably could originate beneath the volcano.

Thus, the seismic activity of Mount Rainier presently cannot be separated from other local minor activity, and no seismic history of the volcano can be compiled. Such a history might be invaluable, however, if the number of small shocks recorded at Longmire increased, suggesting a renewal of volcanic activity.

As molten rock forces its way upward and moves into a volcano, it is accompanied by numerous earthquakes. These increase in number and magnitude as the molten rock nears the surface. If molten rock were to rise into the cone of Mount Rainier, many resulting tremors of small magnitude probably would go unnoticed by people within the Park, but they could be recorded by the seismographs at Longmire. The shocks of small magnitude could be recorded even more fully by sensitive seismographs placed at selected points closer than Longmire to the center of the volcano.

Seismic records from the instruments at Longmire are now being mailed daily to Rasmussen at the University of Washington. If other warning signs of an impending eruption should appear, the seismic records should be carefully examined immediately by Rasmussen or another qualified seismologist, and additional seismographs should be installed at other localities near the volcano for monitoring purposes.

Thermal features

An impending eruption might be anticipated from an increase in the number and temperature of thermal features at the volcano. These features are concentrated at the summit craters, but include warm springs on the flanks of Mount Rainier.

Thermal features at the summit have been known since the first authenticated ascent of the volcano in 1870. They include areas of warm and hot rock and fumaroles along the rims and inner walls of both summit craters, and on the flanks of the summit cone. A geologist who examined the rim of the western crater in 1959 reported a rock temperature of about 174°F in the fumarole zones.

Aerial investigation by Robert M. Moxham of the Geological Survey with infrared radiometers in 1964 revealed areas of thermal anomalies associated with both craters and the flanks of the summit cone. In addition, some possible thermal anomalies were found high on the south flank of the volcano in the vicinity of Gibraltar Rock. The summit of the volcano was reexamined with infrared radiometers in 1966 by Moxham, who found that there had been no change in thermal anomalies since 1964.

Thermal springs are known at Longmire, Ohanapecosh, and on the south flank of the volcano near McClure Rock. At both Longmire and Ohanapecosh, the springs occur in areas underlain by the Ohanapecosh Formation of Tertiary age. Near McClure Rock, springs issue at an altitude of about 6,800 feet from fissures in an east-facing cliff formed by a south-dipping lava flow from Mount Rainier.

At Longmire, the temperature of springs ranged from 51° to 85°F in 1930, according to records of the National Park Service, and temperatures determined by the writer in 1964 ranged from 54° to 73°F. Nonthermal springs in the vicinity had a temperature of 46°F in 1964. At Ohanapecosh, the temperature of springs measured by the writer in 1964 ranged from 100° to 120°F. Temperatures of springs near McClure Rock ranged from 63° to 76°F in 1930, and from 77° to 78°F in 1964. A nonthermal spring in the same vicinity had a temperature of 46°F.

The temperature of one spring near McClure Rock was recorded continuously from August 15 to August 28, 1966. During most of this time, water temperature was between 70° and 77°F. The highest temperature recorded, 78°F, was reached momentarily at noon on August 18. The lowest temperature, 67°F, was reached during the night of August 26-27, during a period of rainfall. The recordings indicate an approximate average diurnal variation of 4.5°F; a daily maximum was generally reached about noon, and a daily minimum at or shortly after midnight.

The thermal springs at Longmire and Ohanapecosh may have a source of heat unrelated to the volcano; the two localities are at a distance of 7.5 and 12 miles, respectively, from the center of the cone. However, the springs near McClure Rock are only 3.5 miles from the center of the volcano, and inasmuch as they occur in rocks of the cone, their heat probably is derived ultimately from areas of heated rock within Mount Rainier. If molten rock rose into the volcano, heat from it might be transmitted to water circulating within rocks of the cone. If this occurred, increased temperatures of the thermal springs near McClure Rock might give early warning of an impending eruption.

Effects of various kinds of eruptions

Mount Rainier is the central feature of a much-visited National Park, and lies at the heads of five major rivers that drain into populated lowlands; thus, a future eruption of the volcano could have serious, if not disastrous, consequences. Within the Park, some existing visitor and maintenance facilities and year-round residences are in locations judged to be potentially hazardous, in a long-term view, from an evaulation of volcanic events that have repeatedly affected these locations within the last 10,000 years. The effects of different kinds of eruptions, and the hazards they might create, are specified in the following discussion, and courses of action and evacuation routes are suggested in the Appendix.

Lava flows

If future lava flows are similar in scale and location to those of the last 10,000 years, their greatest potential threat lies in causing such indirect effects as floods and mudflows. Direct effects will probably be confined to the summit area of the volcano, for no recent flows are known to have been erupted from the base or flanks of the cone. Even if a flow were to be extruded from the flank, it probably would be moderately stiff and sluggish, and would move at a speed of less than 5 miles per hour. The direct danger of a lava flow overwhelming a campground before campers could be evacuated is negligible.

The indirect effects of a lava eruption are a far greater potential hazard. If lava were erupted at the summit, its initial effect would be to melt snow and ice in the summit craters. Downward infiltration of this water to meet the ascending molten rock could lead to steam explosions that might disrupt the summit cone and cause landslides. Bodies of water in the summit craters would also be subject to expulsion by a steam explosion, or could suddenly be released by the rupture of the sides of the summit cone. In either case, floods undoubtedly would result from the large amount of water that would rush down the flanks of the volcano.

Lava erupted onto snowfields or glaciers on the flank of the volcano would cause rapid melting which would also lead to floods on valley floors.

Pyroclastic eruptions

The degree of direct hazard that would be created by an eruption of ash or lapilli would be governed by the rate and duration of the eruption, the location and inclination of the eruptive vent, the intermittent or continuous character of the eruption, the height of the eruption column, and the strength and direction of winds. The six pumice eruptions of Mount Rainier during the last 10,000 years have all produced relatively small volumes of material; the direct effects of a future eruption of ash or lapilli on the same scale, and affecting the same geographic area, would be troublesome but probably not disastrous.

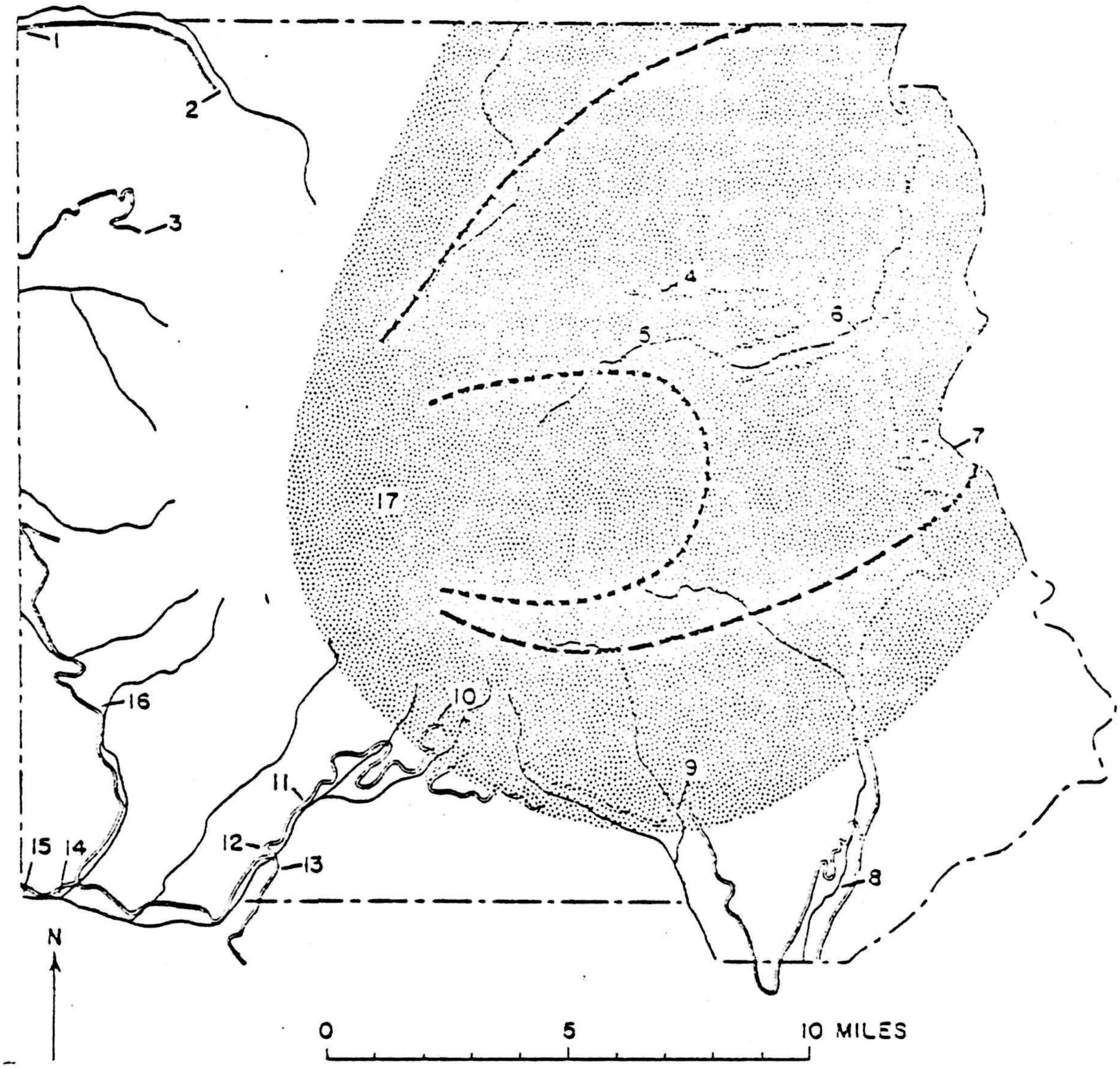
In the past, the coarsest and thickest deposits have accumulated in a sector east of the volcano roughly bounded by lines extending northeasterly and southeasterly from the summit (see figs. 1-4). Yakima Park Visitor Center and White River Campground lie near the northern edge of the sector, and White River Ranger Station and Tipsoo Lake lie near the center. The ranger station and campground at Ohanapecosh lie at the southern edge.

A pyroclastic eruption from a vent on the flank of the volcano, or from an inclined vent at the summit, might result in deposition of coarse pumice within a distance of perhaps as much as 5 miles in some direction from the volcano other than easterly. If the pumice distribution were to be controlled wholly by wind, the height of the eruption column and wind direction and strength would control the shape of the fallout pattern. A narrow, elongate pattern such as that of pumice layer L (see fig. 3) would result from a brief or weak eruption, or one accompanied by strong winds at the altitudes reached by the eruption column. A broader pattern would be expected from a strong eruption, one of long duration, or one that occurred while winds were weak or shifting in direction.

The probable effects of wind in distribution of pyroclastic materials at various times of the year are discussed below. It should be pointed out that these statements apply to a pyroclastic eruption that would continue for several days to several weeks or more, because they are based on average monthly wind directions and velocities. If an eruption were to be of a single day's duration, the distribution pattern might be radically different and almost unpredictable. In general, the average monthly wind directions obtained from high-altitude records (years of 1958 through 1964) of the U.S. Weather Bureau at Seattle, Olympia, and Tatoosh Island in western Washington suggest that fallout from a pyroclastic eruption could be distributed anywhere in a sector extending from the northeast to the southeast during most of the year, with either a broad or narrow pattern.

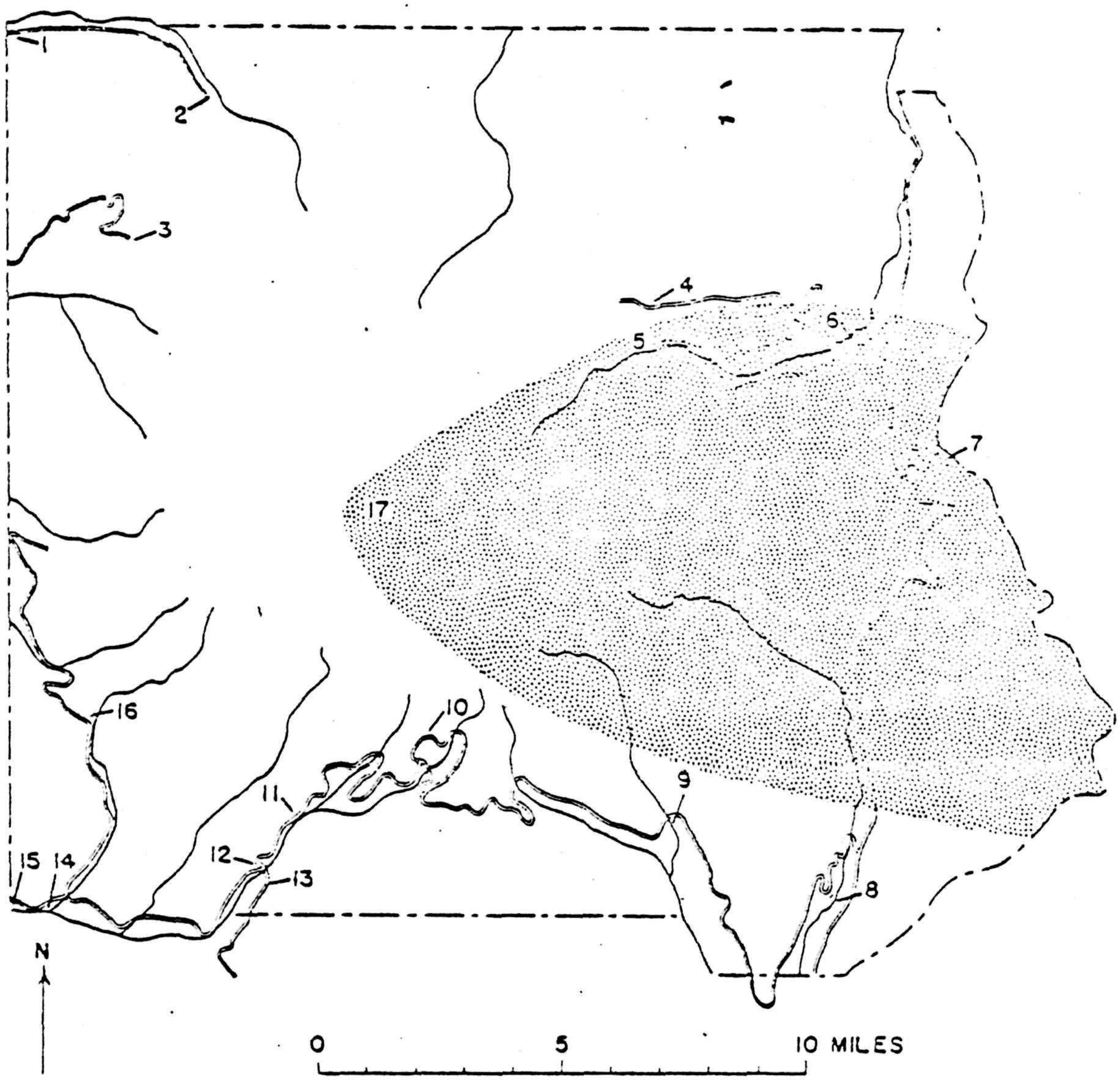
During January, prevailing winds come from the west and northwest at altitudes between 18,000 and 66,000 feet. Winds at 18,000 feet have a monthly average velocity of 20-40 knots, and at 33,000 feet, 50-70 knots. The strength of winds at these altitudes increases the probability of a sharply defined and narrow fallout pattern, especially during a short-lived eruption. Coarsest and thickest deposits could be expected to fall within a sector extending southward from Tipsoo Lake to Ohanapecosh. A significant amount of pyroclastic material could fall as far west as Paradise.

During February, March, and April, the direction of average monthly winds ranges from southwesterly to northwesterly; winds at altitudes below 66,000 feet are slightly more northward than during January.



1. Carbon River Ranger Station
2. Ipsut Creek Campground
3. Mowich Lake Campground
4. Yakima Park Ranger Station, Campground, Visitor Center
5. White River Campground
6. White River Ranger Station
7. Tipsoo Lake Picnic Ground
8. Ohanapecosh Ranger Station, Campground, Visitor Center
9. Box Canyon
10. Paradise Ranger Station, Visitor Center, Campground, Hotel
11. Cougar Rock Campground
12. Longmire Park Headquarters
13. Longmire Campground
14. Sunshine Point Campground
15. Nisqually Ranger Station
16. Tahoma Creek Campground
17. Summit Crater

Figure 1.--Area within Park (shown by pattern) covered by pumice layer C to a depth of 1 inch or more. Long dashed lines indicate boundaries of area covered by 3 inches of pumice or more, and short dashed line, 6 inches of pumice or more. Pumice layer C is about 2,000 years old.



1. Carbon River Ranger Station
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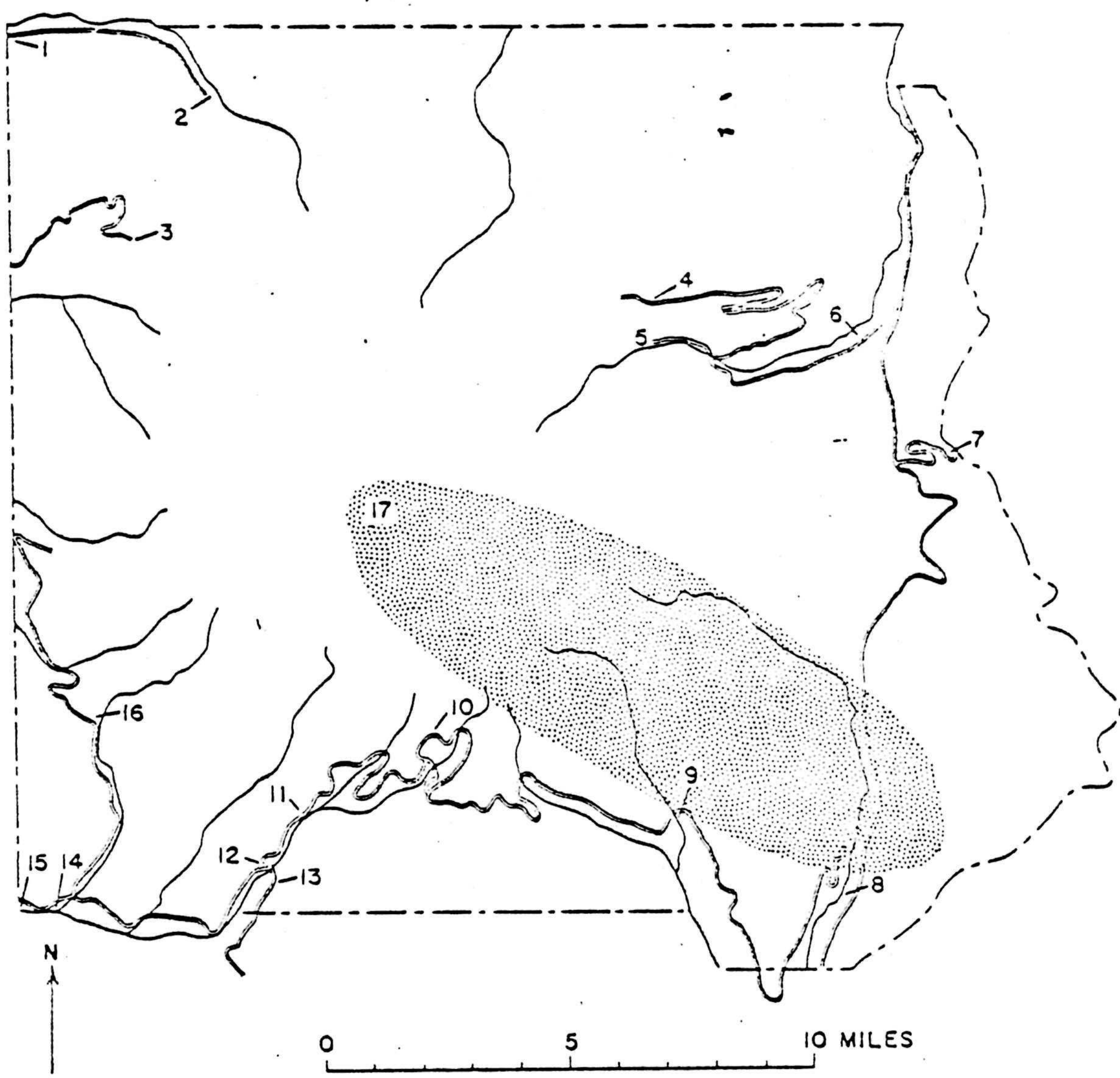
5. White River Campground
6. White River Ranger Station
7. Tipsoo Lake Picnic Ground
8. Ohanapecosh Ranger Station, Campground, Visitor Center
9. Box Canyon
10. Paradise Ranger Station, Visitor Center, Campground, Hotel
11. Cougar Rock Campground
12. Longmire Park Headquarters
13. Longmire Campground
14. Sunshine Point Campground
15. Nisqually Ranger Station
16. Tahoma Creek Campground
17. Summit Crater

Figure 2.--Area within Park (shown by pattern) covered by pumice layer D to a depth of 1 inch or more. The pumice is between 5,000 and 6,000 years old.



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6. White River Ranger Station
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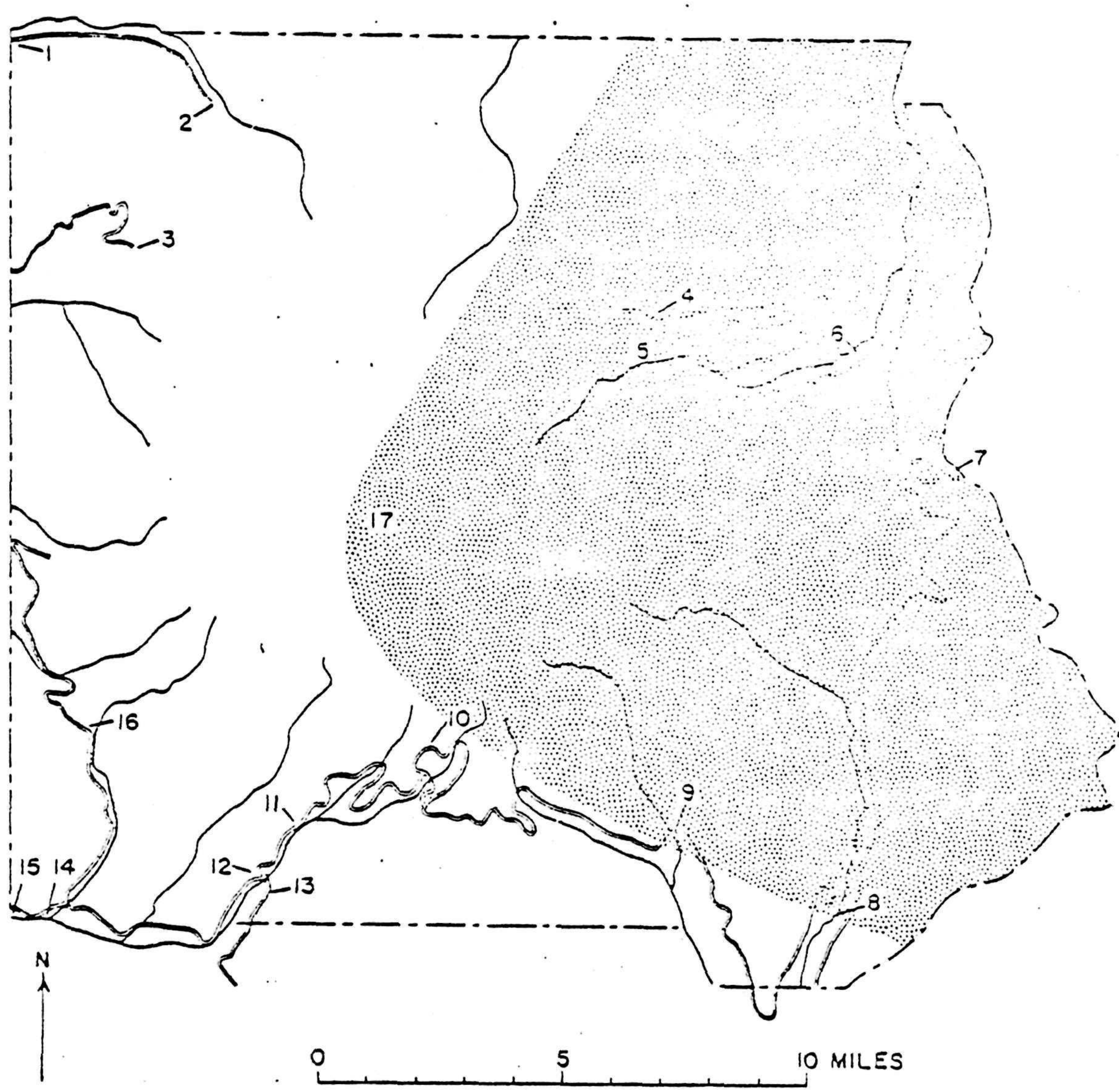
9. Box Canyon
10. Paradise Ranger Station, Visitor Center, Campground, Hotel
11. Cougar Rock Campground
12. Longmire Park Headquarters
13. Longmire Campground
14. Sunshine Point Campground
15. Nisqually Ranger Station
16. Tahoma Creek Campground
17. Summit Crater

Figure 3.--Area within Park (shown by pattern) covered by pumice layer L to a depth of 1 inch or more. The pumice may be about 6,000 years old.



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13. Longmire Campground
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15. Nisqually Ranger Station
16. Tahoma Creek Campground
17. Summit Crater

Figure 4.--Area within Park (shown by pattern) covered by pumice layer R to a depth of 1 inch or more. The pumice probably is 10,000 or 11,000 years old.

At an altitude of 18,000 feet, winds have an average monthly velocity of 15-35 knots, and at 33,000 feet, 25-60 knots. Fallout of coarsest and thickest deposits could be expected within a sector extending southward from Yakima Park to Ohanapecosh.

The average monthly winds during May are mostly westerly and southwesterly. Winds at an altitude of 18,000 feet have average monthly velocities of 10-25 knots, and at 33,000 feet, 10-40 knots. At an altitude of 66,000 feet, winds characteristically are variable in direction and weak. Coarsest and thickest pyroclastic deposits could be expected to fall within a sector extending southward from Yakima Park to Tipsoo Lake. Somewhat lower average wind velocities might permit fallout of coarsest and thickest material relatively close to the volcano and greater lateral spreading than during months characterized by stronger winds.

During June, average monthly winds are mostly westerly and southwesterly. Although generally stronger than May winds, they are variable in strength. At an altitude of 18,000 feet, average monthly velocities range from less than 5 to 30 knots. At 33,000 feet, velocities are as high as 55 knots, but during some years the average June winds are from the east and have a velocity of less than 5 knots. These weak easterly winds are especially characteristic at an altitude of 66,000 feet. Fallout of thickest and coarsest material can be expected in a sector extending from Yakima Park southward a short distance beyond Tipsoo Lake.

Both July and August are characterized by westerly and southwesterly winds from 18,000 to 33,000 feet. The average monthly velocities of these winds range from 20 to 30 knots at 18,000 feet, and 30 to 40 knots at 33,000 feet. Altitudes of 66,000 feet and higher are featured by easterly winds that mostly have average monthly velocities of 5 knots or less. These winds might cause pyroclastic material to fall west of the volcano if the eruption column reached a sufficiently high altitude. During both months, fallout of coarsest and thickest material could be expected in the sector bounded by Yakima Park and Tipsoo Lake.

Average monthly winds during September and October are from the southwest, west, and northwest. Average monthly wind velocities range from 15 to 40 knots at an altitude of 18,000 feet, and from 35 to 60 knots at 33,000 feet. Accumulation of coarsest and thickest deposits could be anticipated east of the volcano in a sector bounded by Yakima Park and Ohanapecosh.

During November and December, average monthly winds are from the west and northwest below an altitude of 66,000 feet. At 33,000 feet these winds have average monthly velocities of 35-75 knots. At altitudes of 80,000 feet and higher, winds ranging from 5 to 25 knots average velocity commonly blow from the northeast during both months. Fallout of coarsest and thickest material could be expected in a sector extending from Tipsoo Lake southwestward to Box Canyon. Yakima Park is least likely to receive thick pumice fallout from an eruption during these two months, but a significant amount might fall as far west as Paradise. Strong winds during November and December below an altitude of 66,000 feet probably would result in a narrow, well-defined fallout pattern.

Some specific hazards that would be created by a pyroclastic eruption are as follows:

1. Breathing of ash. Exposure for a few hours is not likely to be harmful; the effects would be similar to those of a dust storm. Some protection could be obtained by holding a dampened cloth over the face.
2. Breathing of gases resulting from the eruption. These could be toxic if inhaled long enough in sufficient concentration. This hazard would decrease rapidly downwind from the volcano, and would not exist in other directions.
3. Under some conditions, burns might be received from falling hot lapilli and ash. This hazard could be reduced by taking shelter in a building, car, or even beneath a tree.
4. Pyroclastic material might create traffic hazards by causing poor visibility. Ash might coat windshields and headlights with a thin, opaque film. Ash accompanied by rain would result in slippery roads, so that even though the ash were thin, the steeper grades in the Park would be hazardous.
5. If deposition of ash and lapilli were rapid and accompanied by rain, loading of roofs might cause collapse, although it is doubtful that the weight would exceed that of a heavy wet snowfall.
6. Floods of ash-laden water and mudflows might result from heavy rainfall accompanying the eruption.
7. Ash falling into streams and reservoirs used for water supplies could cause temporary acidity and turbidity.

The potential indirect effects of a pyroclastic eruption include expulsion of lakes in the summit craters of the volcano, and the other phenomena associated with such lakes mentioned previously under lava flows. These effects would be confined chiefly to valley floors.

Airfall of old rock debris from steam explosions

A steam explosion that projected fragments of previously cold, solid rock into the air is believed to have occurred at least once at Mount Rainier, probably a little more than 5,000 years ago. In contrast to pumice, which can be transported long distances by wind because of its light weight, solid rock debris tends to fall relatively near the point of explosion. Even so, fragments as large as 18 inches in diameter, which are thought to have originated in this way, are found near the eastern end of Yakima Park. Their place of origin on the volcano is not known.

If a steam explosion projected rock fragments high into the air, the best defense against being struck would be to move immediately to the lee side of a boulder, cliff, or even a very large tree.

Hot debris avalanches

Avalanches of very hot rock debris could result from the movement of molten rock into the summit area of the volcano. Explosions could eject blobs of lava to form bombs, blocks, and ash that might accumulate until masses began sliding down the flank of the volcano. Avalanches of this sort would tend to follow depressions, and thus would move farthest along valleys. They probably would take the form of a single mass, or successive masses, of hot fragments of many sizes rolling, sliding, and flowing from the side of the volcano onto the adjacent valley floors under a great pall of dust. Because of the large vertical drop from the summit of the cone, and the small frictional resistance offered by the surface of glaciers, avalanches of rock debris could move very swiftly, even at velocities greater than 100 miles per hour.

Valley floors would be the most hazardous locations if hot avalanches occurred during an eruption, and areas affected might extend to a height of several hundred feet on the valley sides. Accompanying dust clouds, which probably would carry toxic fumes, might extend more than a thousand feet higher. Because of the extreme speed and high mobility provided by entrapped and heated air, avalanches of this sort might travel to distances of 8 miles or more from the summit of the volcano.

If from a vantage point in a nearby valley floor, such an avalanche were observed starting high on the volcano, evacuation by the fastest means available would be mandatory because of the probable speed of the avalanche. In general, the only safe evacuation route from such a location on a valley floor would be directly down-valley.

A potential hazard that might be caused by such an avalanche is that of a forest fire started by the hot rock debris.

Cold debris avalanches and mudflows

Avalanches of cold rock debris can be caused by earthquakes, by explosions of steam trapped within the volcano, and by other types of volcanic explosions. Contributing factors include undercutting of cliffs by glaciers, and weakening of rock by long-continued freeze and thaw or by hot volcanic gases and solutions. Many of the avalanches in the past have been sufficiently wet to become mudflows that have moved many miles down the valley floors. The avalanches of rock debris from Little Tahoma Peak in 1963, however, stopped on the floor of the White River valley a few miles from the place of origin.

Cold avalanches of rock debris may not be accompanied or preceded by any apparent volcanic activity, and thus could occur wholly unexpectedly. The effects of cold avalanches are similar to those of hot avalanches, although toxic fumes and heat will be absent. A possible secondary hazard created by a cold avalanche is the damming of a river, followed by a sudden release of the lake to cause floods.

Cold avalanches are not exclusively volcanic phenomena, although they probably occur more often at a volcano than elsewhere in the same region simply because of the combination there of extremely steep slopes; abundance of snow, ice, and accumulations of loose rock debris; relatively weak rock; and intermittent volcanic activity.

Once an avalanche of rock debris has started, little can be done other than to move as quickly as possible farther downvalley, or higher on the valley side. It is especially important to recognize the possibility that one avalanche will be followed by another, or by several more, any of which might be as large or larger than the first. For instance, of the seven avalanches of rock debris that originated at Little Tahoma Peak in 1963, the third in succession was the largest. For this reason, after an avalanche has occurred, the area affected should be approached only with extreme caution, and even then probably only after several days have gone by without additional avalanches.

Avalanches of cold rock debris in the past have created enormous mudflows in the valleys of Nisqually River, Tahoma Creek, North and South Puyallup Rivers, and White River and its West Fork (fig. 5). Near the volcano, some of these mudflows temporarily submerged valleys to depths of 1,000 feet or more. The avalanches that led to the mudflows apparently originated in areas of rock high on the volcano that had been weakened and extensively altered to clay by gases and solutions. The largest known mass of similar rock and clay that still remains high on the volcano forms part of the east wall of Sunset Amphitheater, at the head of the valleys of the North and South Puyallup Rivers and Tahoma Creek. Masses of this rock and clay have slid off in the recent past to form mudflows; Tahoma Creek Campground is situated on a mudflow deposit that originated in this manner a little more than 400 years ago. An avalanche from Sunset Amphitheater that apparently did not form a mudflow lies on top and just beyond the end of Tahoma Glacier in the South Puyallup River valley. The age of trees growing on the deposit suggests that it probably occurred shortly before 1930.

Mudflows also are caused by very heavy rainfall that occurs within a short time. For example, mudflows were created in the Kautz Creek valley in early October 1947 as a consequence of heavy rainfall, which included 0.21 inch on September 25, 1.10 inches on September 28, and culminated in 5.85 inches on October 2. On October 2, discharge of both Kautz Creek and the Nisqually River increased greatly, and both streams became muddy and were carrying large boulders. Some time during the night of October 2-3, the character of Kautz Creek changed from a flood to a broad, sluggish river of mud that was described as having the consistency of wet concrete, carrying with it vegetation and boulders as large as 13 feet in diameter. R. K. Grater, then Chief Park Naturalist, attributed the mudflows to high runoff of rainfall from slopes adjacent to Kautz Glacier, and to the release of a lake dammed by ice and debris in a valley constriction just below the glacier. Large-scale sliding and flowing of saturated masses of loose rock debris from glacial moraines on the canyon walls above and downvalley from Kautz Glacier undoubtedly contributed a considerable amount, if not a major part, of the solid material in the mudflows. Most of this material was deposited in the lower, wider part of the Kautz Creek valley, although some was transported by the Nisqually River and deposited in Alder Reservoir, 16 miles farther downstream. At the junction of the Nisqually River and the Kautz Creek valleys, the mudflows built a fan of debris several tens of feet thick, obliterating the former flood plain, and burying the Nisqually Entrance Road.

Small mudflows occur from time to time even during clear, dry weather. On August 23, 1961, a short-lived mudflow was observed in the channel of Kautz Creek by Park Service personnel. It probably originated from the release of unusual amounts of melt water by Kautz Glacier, perhaps owing to the failure of a small lake dammed by ice or debris. The increased discharge of Kautz Creek probably caused removal of loose rock debris in the channel and locally resulted in sideways erosion into loose material in the channel walls. If the stream flow had been appreciably greater and of longer duration, wholesale sloughing of the channel walls probably would have resulted from undercutting, and larger mudflows might have been formed.

A potential source of future mudflows caused by precipitation lies in the loose, unvegetated glacial moraines that are plastered against the steep walls of almost every valley near the glaciers. These moraines have mostly been abandoned by glaciers since 1910, and it may be at least another 50 years before they become adequately stabilized.

Flooding of valleys in the Park, sometimes accompanied by relatively small mudflows, frequently is caused by rapid melting of a deep snow during a period of rising temperature, warm winds, and rain. In the past, these conditions have generally occurred during the months of October through January. Inasmuch as the phenomena that lead to these floods are meteorological, similar floods should be expected in the future when the weather conditions are repeated.

Floods and mudflows of small volume are confined to the lowest parts of the valley floors; thus, if either seems imminent, only evacuation to higher ground is required. But if another mudflow of extremely large volume should occur, comparable to the largest mudflows of the past, its speed and depth might result in an almost hopeless situation for people on valley floors, unless immediate rapid evacuation downvalley by car were possible.

Lateral blasts of ash-laden steam

Perhaps one of the greatest potential direct hazards in the Park from volcanic activity is that of a lateral blast of hot ash, steam, or both. In 1915 such a blast devastated an area of about 3 square miles on the northeast side of Lassen Peak in northern California, but caused no loss of human life. Deposits from this type of eruption have not yet been recognized at Mount Rainier. However, it is possible that the deposits exist but are not distinctive enough to be readily differentiated from other volcanic deposits.

The direct effects of hot volcanic blasts could extend to a distance of at least 5 miles from the site of the eruption, with little regard for topography. If such a blast were to occur in the future, it would take place so quickly that there would be little or no chance of escape. However, a lateral blast probably would be preceded by hours or days of other, less violent kinds of volcanic activity. Thus, the safest procedure would be to evacuate and close all areas in the Park within the destructive range of a lateral blast during the entire course of an eruption.

Evaluation of potential hazards at existing Park facilities

Table 1 shows the direct and indirect hazards from some kinds of volcanic activity at various places within Mount Rainier National Park; the hazards at each locality are interpreted from phenomena that have actually affected these places during post-glacial time, or that have affected other places in similar topographic positions and at similar distances from the volcano. The qualitative terms that express the relative degree of hazard (high, moderate, low, and none) to people at the specified locations are arbitrary, and are assigned according to the effects that might be anticipated if a substantial eruption should occur in the future. The degree of hazard is based on such factors as distance and direction from the volcano, topographic setting of the locality, and the number of times the phenomenon has occurred in the past.

The topographic setting is especially significant for areas on or closely adjacent to valley floors, because eruptions during the last 10,000 years have affected valley floors more often than any other areas in the Park. The degree of potential hazard decreases with height; sites only a few feet higher than the present stream are susceptible to inundation even by floods of modest size that are sometimes caused by heavy precipitation. Sites 30 feet or higher above the stream probably would be covered only by major floods or mudflows resulting from volcanism of some kind, or by an avalanche of rock debris if they are within a few miles of the base of the volcano. The size and shape of the valley adjacent to a site also is important; a narrow stream channel obviously will accommodate less flowing water or mud than a broad flood plain.

Distance from the volcano also governs the relative degree of hazard from floods, mudflows, and avalanches, as well as from pyroclastic deposits and hot lateral blasts. Direction from the volcano is important because the wind blows from a westerly direction during nearly all of the year, and this would govern the distribution of pyroclastic deposits.

The number of times a certain phenomenon has occurred in the past at a given place may have some bearing on the likelihood that phenomenon will occur again there in the future. For example, some

Table 1.--Evaluation of kind and degree of potential hazards at various locations within the Park

	Direct hazard					Indirect hazard
Location within Park	Lava flow	Pyro-clastic eruption	Airfall of rock debris from explosion	Hot debris ava-lanche	Cold debris ava-lanche	Floods and/or mudflows
Carbon River Ranger Sta.	none	low	none	none	none	high
Ipsut Creek Campground	low	low	none	low	low	high
Mowich Lake Campground	none	low	none	none	none	none
Yakima Park Visitor Center, Campground	none	high	moderate	none	none	none
White River Campground	low	high	high	high	high	high
White River Ranger Sta.	none	high	none	low	none	moderate
Tipsoo Lake	none	high	none	none	none	none
Ohanapecosh Visitor Center, Campground	none	high	none	none	none	low
Box Canyon	none	high	none	low	none	high
Paradise Visitor Center, Campground	low	moderate	moderate	moderate	moderate	none
Cougar Rock Campground	low	low	low	high	high	high
Longmire	low	low	low	moderate	low	high
Sunshine Pt. Campground	low	low	none	low	none	high
Tahoma Creek Campground	low	low	moderate	high	high	high

valleys have been inundated by mudflows more often than others. The South Puyallup River and Tahoma Creek valleys, in particular, have been buried many times by mudflows. The source of the mudflows is in a mass of clayey rock in Sunset Amphitheater, which presumably will avalanche again and cause more mudflows in the future.

Tahoma Creek Campground is thought to be in an especially hazardous location. The campground is only a few feet higher than the nearby channel of Tahoma Creek, and there is little doubt that the campground would be inundated if a flood or mudflow of even modest dimensions moved down the valley.

The campground is relatively isolated and is without telephone service. Campers could be notified of a need for evacuation only by someone who drove up the West Side Road from the Nisqually Entrance Road, a distance of about 4 miles.

Some consideration should be given to relocating the campground in a potentially less hazardous area. If the campground is permitted to remain where it is, it should not be expanded, because of the possibility of subjecting additional campers to a potentially hazardous situation.

A possible alternative site for a campground on the west side of the Park is in the vicinity of the St. Andrews Patrol Cabin. The valley floor of St. Andrews Creek has never been inundated by a flood or mudflow during the last 10,000 years, probably because the creek does not originate on the slopes of the volcano proper. The only pumice at the St. Andrews site is not from Mount Rainier but from Mount St. Helens volcano, 50 miles away. Although a view of Mount Rainier is not available from the St. Andrews location, the site has the charm of a fine forest and a lovely clear stream.

Sunshine Point Campground is situated on the flood plain of the Nisqually River a short distance below the mouth of Tahoma Creek. The campground site is 6-8 feet above the Nisqually River and thus is subject to flooding. It is doubtful that an alternative site that would be both suitable for a campground, and in a potentially less hazardous location, exists in the same general area of the Park. If the Sunshine Point Campground is permitted to remain in use, it should not be expanded.

Longmire Campground is currently used only when the capacity of Cougar Rock Campground is exceeded. The campground at Longmire is situated on a deposit formed by a flood about 300 years ago. The campground area is 5-10 feet higher than the surface of the adjacent channeled and unvegetated flood plain of the Nisqually River. The small margin of safety afforded by this difference of height is not regarded as adequate in the event of a future flood or mudflow of even moderate size. It is recommended that the use of the campground be restricted, as is the current practice. It should not be restored to full use in the future, in response to increasing demand for campground space, because of its potentially hazardous location.

Cougar Rock Campground is located on a terrace about 25-30 feet above the adjacent flood plain of the Nisqually River. Forming the terrace is a flood and mudflow deposit between 500 and 3,000 years old. Since the deposit was formed, the Nisqually River has eroded a trench through it that is about 300 feet wide. Because of its height, the terrace probably is as safe as any location suitable for a campground within this part of the valley. However, any campground on the floor of a major valley, this close to the volcano, is in a potentially hazardous location.

Ipsut Creek Campground is situated on a flood plain only a few feet above the Carbon River and thus is susceptible to being flooded by high water. A suitable alternative, potentially less hazardous, site for the campground on the valley floor is not known. The Carbon River valley floor is not known to have been buried by a mudflow more than once during the last 10,000 years; thus, this potential hazard may be less critical than in some other valleys in the Park.

Ohanapecosh Campground and Visitor Center are in a location that is relatively less hazardous than most other valley-floor facilities in the Park. Most of the campground lies on a terrace estimated to be about 40 feet higher than the Ohanapecosh River, and the site is at a greater distance, about 11 miles, from the summit of the volcano than that of any other campground. The bridge that connects the two parts of the campground has at least 35 feet of vertical clearance over the river, and the estimated cross-section area beneath it is at least 2,400 square feet.

The terrace on which White River Campground lies is about 30 feet above the White River flood plain at its upstream end, and about 45 feet at the downstream end. At the present upstream loop of the campground the terrace surface is 35 feet above the flood plain. The terrace is formed of flood and mudflow deposits between 500 and 2,000 years old. The height of the campground is adequate to prevent inundation by small floods, although the access road might be submerged and blocked by flood deposits at some places where it lies only a few feet higher than the flood plain.

One potential future hazard at the campground was dramatically illustrated only a few years ago, when an avalanche of rock debris originating in a rockfall at Little Tahoma Peak came within 2,000 feet, after already having moved 4.3 miles. There is no known way to predict future occurrences of this sort, and there is no reason to believe that even larger slides caused by similar rockfalls could not occur in the future and reach the campground.

Being downwind from the volcano and very close to it, the campground could hardly escape some kind of danger if an eruption occurs in the future. The campground has recently been expanded and improved, but future expansion in response to increasing need is not recommended. If additional camping space is needed in the future, a new site should be chosen farther downvalley, perhaps in the lower end of the Fryingpan Creek valley, or on the south side of the White River valley between Fryingpan Creek and Shaw Creek.

White River Ranger Station is situated on a terrace at least 100 feet above the adjacent White River flood plain. Although this site has been inundated by mudflows at least twice during the last 10,000 years, its height above the valley floor indicates that it would be affected in the future only by a mudflow of catastrophic proportions. If the ranger station and associated maintenance buildings are relocated, a safer site should be found, not one that is lower with respect to the valley floor and thus potentially more hazardous than the present location.

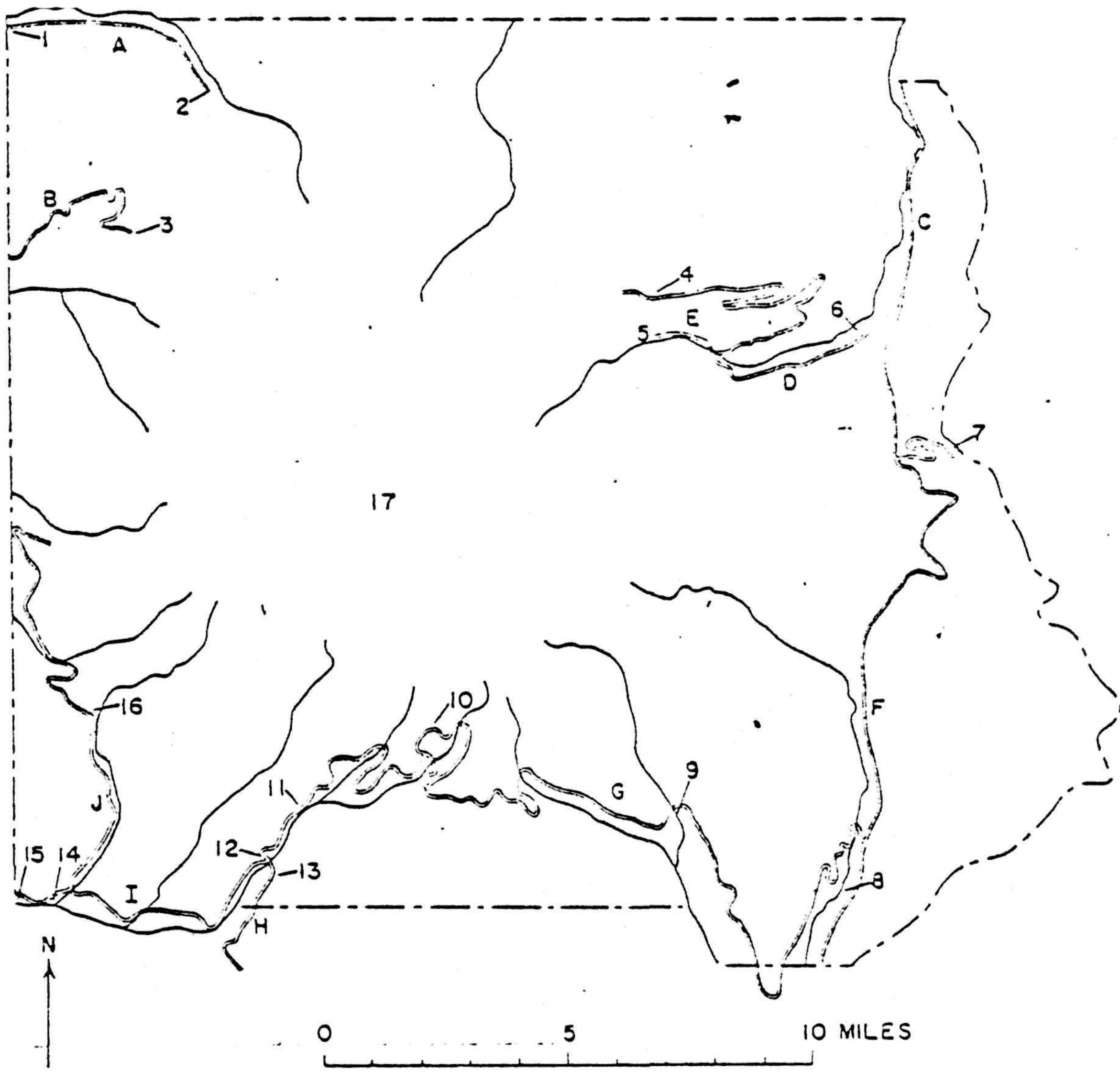
Evacuation routes

Evacuation routes from various locations within the Park, to be used in the event of a future eruption, are described in the Appendix. These routes are recommended after a consideration of such pertinent factors as the distance of travel necessary along roads on valley floors, the height of these roads above present rivers, the number and vertical clearance of bridges to be crossed, the variety of potential hazards along the route, distance of the route from the volcano, and location of the route with respect to areas likely to be covered with pyroclastic deposits.

The routes recommended are not in all cases the most direct routes away from the volcano. Evacuation of Longmire and Cougar Rock Campground westward by way of the Nisqually Entrance Road (fig. 6) would result in crossing Kautz and Tahoma Creeks. The highway bridges over both creeks might be destroyed by floods of relatively small volume, so that people in vehicles might be trapped on the valley floor between the streams. A rough measurement of the dimensions of the bridge at Kautz Creek in November 1966 revealed a vertical clearance above the stream of about 12 feet, and a cross-section area beneath the bridge of about 500 square feet. The foundation of the bridge is on gravel. Upstream from the bridge the channel of Kautz Creek is only a few feet lower than the adjacent flood plain in places; if a flood should occur, the creek might readily create a new channel on the flood plain and bypass the highway bridge. The small amount of clearance beneath the bridge suggests that the stream channel here could be easily dammed by trees brought down-valley by a flood.

The bridge at Tahoma Creek has a vertical clearance of about 12 feet and the cross-section area beneath it is about 800 square feet. It, too, is constructed on gravel. The flood plain here is slightly higher in the middle than on the west side. The present stream channel itself is about 10 feet higher than a low area along the base of the valley wall just west of the bridge. If a high flood should occur, Tahoma Creek could find a new, lower course west of its present channel, the bridge would be bypassed, and the Entrance Road would be inundated.

Evacuation of Longmire and Cougar Rock Campground by proceeding northward up the Nisqually River valley would temporarily require approaching the volcano. Insofar as potential hazards from mudflows



1. Carbon River Ranger Station
2. Ipsut Creek Campground
3. Mowich Lake Campground
4. Yakima Park Ranger Station, Campground, Visitor Center
5. White River Campground
6. White River Ranger Station
7. Tipsoo Lake Picnic Ground
8. Ohanapecosh Ranger Station, Campground, Visitor Center
9. Box Canyon
10. Paradise Ranger Station, Visitor Center, Campground, Hotel
11. Cougar Rock Campground
12. Longmire Park Headquarters
13. Longmire Campground
14. Sunshine Point Campground
15. Nisqually Ranger Station
16. Tahoma Creek Campground
17. Summit Crater

A. Carbon River Entrance Road
B. Mowich Lake Road
C. U. S. Highway 410
D. White River Entrance Road
E. White River Campground Road
F. State Highway 143
G. Stevens Canyon Road
H. Skate Creek Road
I. Nisqually Entrance Road
J. West Side Road

Figure 6.--Roads, visitor facilities, and other features in Park.

and floods on the valley floor are concerned, the most dangerous point along the highway probably is at a point near the center of section 22, at the bottom of a hairpin curve. The road surface here is about 22 feet above the Nisqually River and about 14 feet above very recent bouldery flood deposits. Farther upvalley, the bridge over the Nisqually River has a maximum vertical clearance of about 70 feet above the river and probably is safe from any potential hazard other than a very large rock-debris avalanche or mudflow.

Evacuation eastward from Longmire and Paradise Park would require crossing the Paradise River either just above Narada Falls, or farther upstream just east of Paradise Park. The upstream bridge was not examined by the writer. The lower bridge has a vertical clearance of only 4-8 feet, and the effective cross-section area beneath it probably is no more than 150 square feet. Even minor flooding of the Paradise River seemingly would render this bridge impassable; it is especially susceptible to being blocked by flood debris of any kind. The amount of clearance and cross-section areas beneath bridges along the Stevens Canyon Road are more satisfactory.

Evacuation of Longmire by way of the Skate Creek Road requires crossing the Nisqually River bridge at Longmire. This bridge could be swept away either by a very large flood or by a mudflow of moderate size. The bridge has vertical clearance of about 20 feet, a cross section area beneath it of about 3,000 square feet, and both abutments are on bedrock. If Longmire and Longmire Campground were to be evacuated by way of the Skate Creek Road, the locked gates at the south boundary of the Park would have to be opened.

Future planning with respect to volcanic hazards

Of all the areas in Mount Rainier National Park that are now being utilized for various kinds of facilities, valley floors are potentially the most hazardous. They are hazardous because floods and mudflows can occur at any time, and because the most diastrous predictable effects of any future eruption of the volcano would be concentrated on the valley floors.

In the future, consideration should be given in planning to locating new campgrounds and maintenance facilities in areas least likely to be damaged by geologic phenomena. In general, valley floors directly east of and relatively near the volcano are potentially the most hazardous areas in the Park with respect to the probable direct and indirect effects of a future eruption. The least hazardous locations are those that are hundreds of feet above the floors of the major valleys on the northwest, west, and southwest sides of the Park. Site selection for new facilities anywhere in the Park should be carefully examined and evaluated by a qualified geologist, having in mind the degree of potential hazard from future eruptions.

APPENDIX

(Instructions to be given to rangers and ranger naturalists)

PROCEDURES TO FOLLOW IN CASE OF A VOLCANIC ERUPTION

Mount Rainier is a dormant, but not extinct, volcano. It has not erupted new lava or volcanic ash since white man first saw it. However, from time to time during the last 10,000 years, it has thrown out pumice and volcanic bombs, and during the last 2,000 years lava flows have built a small cone at the top of the volcano. In addition, volcanic explosions or earthquakes have repeatedly caused enormous masses of clay and rock to slide from the top and sides of the mountain. These masses, when mixed with water, have formed mudflows tens to hundreds of feet deep in nearly every valley that heads at the volcano.

If an eruption should begin, natural curiosity will lead some people to try to see what is happening. This should be strongly discouraged. Visitors should be directed to leave the Park immediately along one of the recommended evacuation routes. They should be warned not to approach the volcano on foot or by car, except where an evacuation route locally leads toward the volcano.

All campgrounds and visitor centers in the Park are so far away from the volcano that there is relatively little direct danger from lava flows. However, on all valley floors and low terraces there is a potential hazard from floods and mudflows that probably would accompany an eruption. Floods and mudflows might cover or wash away some campgrounds and roads, sweep away cars, knock down trees and buildings, and disrupt telephone lines. In addition, earthquakes or volcanic explosions might shake down large avalanches of ice and rock that could move at speeds greater than 100 miles per hour. It is chiefly because such hazards might accompany an eruption that visitors should be directed to leave the Park at once.

It will not be possible to determine immediately whether an eruption will be on a large or small scale. Furthermore, it cannot be predicted whether an eruption will be preceded by a number of warning signs over a period of many hours or even days. Some kinds of eruptions can occur without any warning whatever.

Because of these uncertainties, the safest approach is to take a pessimistic view. A series of definite warning signs, given below, should be regarded as indicating that a major eruption either has already begun or could take place within the next few hours.

1. Loud explosions and rumbling noises from the volcano.
2. Clouds of ash, steam and smoke rising above volcano.
3. Repeated earthquakes.
4. Repeated avalanches of ice and rock on sides of volcano.
5. Red glow in sky over volcano, or above any other place where molten rock reaches the land surface.

6. Flooding of rivers when not related to rainfall or rapid melting of snow caused by warm weather. Flooding will first be signaled by increase in noise of boulders rolling along stream beds and by trembling of ground caused by the rolling boulders.

Evacuation routes and procedures that should be followed at various locations within the Park are given on the following pages. In the event of a future eruption, the main hazard could be that of wholesale panic. In this regard, it is appropriate to repeat a statement made by Ray E. Wilcox of the U.S. Geological Survey: "The major damage and human suffering from a volcanic eruption often may be due less to physical than to psychological factors, such as panic and fear of the unknown, and usually such suffering is entirely unnecessary."

Further reading that is recommended is U.S. Geological Survey Bulletin 1238, "Volcanic hazards at Mount Rainier, Washington," and Bulletin 1028-N, "Some effects of recent volcanic ash falls with especial reference to Alaska."

Longmire Visitor Center and Park Headquarters

The main hazards at Longmire are floods and mudflows. There also is a possibility of pumice falling if there is a northeasterly wind, but winds from this direction are rare. Alternative evacuation routes are listed below in order of preference. If a pumice eruption should begin while a strong northwest wind is blowing, advice should be requested from rangers at Box Canyon and Ohanapecosh concerning hazard from pumice along the Stevens Canyon Road. If pumice fall is so heavy that visibility is poor and road is blanketed with pumice, people should be directed to stay in the Paradise area.

1. If an eruption starts, or if there are definite warning signs, evacuate all personnel.

2. If reconnaissance up the Nisqually River valley indicates that the road is passable, people at Longmire could be evacuated via the Stevens Canyon Road and Ohanapecosh. If this route were used, a ranger with a radio should be stationed at the bridge over the Nisqually River to warn of a possible high flood crest or mudflow coming down the valley.

3. If a ranger were stationed at the Nisqually River bridge with a radio to give warning of a flood crest or mudflow, Longmire could be evacuated by way of the bridge to Longmire Campground and Skate Creek Road.

4. If rangers with radios were stationed at Kautz Creek and Tahoma Creek to give warning of floods, evacuation could follow the Nisqually Entrance Road. However, because of the possibility of a sudden flood or mudflow while the road was being used, this would still be a relatively hazardous evacuation route and less preferable than the Stevens Canyon Road.

5. If Longmire Campground is in use, direct campers to evacuate campground by way of Skate Creek Road to Packwood.

6. If all roads leading from Longmire are impassable, prepare to walk to Rampart Ridge along foot trail, carrying blankets, food, and

water. Do not go northeast along the ridge toward Van Trump Park; danger increases as the volcano is approached.

7. Advise State Highway Patrol to close U.S. Highway 410 to eastbound traffic at Enumclaw, and to close State Highway 706 to eastbound traffic at Elbe.

8. Warn responsible official in Orting and Sumner of the possibility of floods and mudflows in the Puyallup River valley.

9. Warn responsible officials in Auburn and Puyallup of the possibility of floods in the White River valley, and advise Corps of Engineers maintenance personnel at Mud Mountain Dam.

10. Warn Forest Service personnel, communities, and Tacoma City Light personnel at Alder Dam that there is danger of flooding of the Nisqually River.

Nisqually Ranger Station

The main hazard at this place is from flooding by the Nisqually River, although there also could be mudflows.

1. If notified that an eruption has started, or seems imminent, (a) go to Sunshine Point Campground and evacuate campers. Direct them westward toward Ashford. (b) Go to Tahoma Creek Campground and evacuate campers. Direct them to go south to the Entrance Road, then west to Ashford. If Tahoma Creek rises very swiftly, it may be necessary to evacuate campers to Round Pass.

2. If the Nisqually River rises enough so that the road is submerged at the Nisqually Ranger Station, advise Longmire that the Entrance Road is impassable.

3. Do not permit visitors to enter Park if an eruption has begun.

Cougar Rock Campground

The chief hazards at this campground are floods and mudflows, although there is also a possibility of avalanches of rock debris and fall of pumice.

1. If an eruption begins, or if the Nisqually River begins to flood, advise campers to prepare to leave campground immediately.

2. Determine if road to Ricksecker Point is passable. If it is, evacuate campers eastward via Stevens Canyon Road to Packwood or White Pass. If it is not, evacuate people downvalley toward Nisqually Entrance only if advised by Longmire that the road is passable.

3. If the highway is impassable in either direction, advise people to remain where they are, but to prepare to walk to safe ground. If the Nisqually River begins to flood the campground, or if a series of mudflows begins, people should be led along Wonderland Trail to Rampart Ridge, carrying with them blankets, food, and water. Do not take trail northeastward on top of Rampart Ridge--do not go to Van Trump Park, because danger increases as the volcano is approached.

Paradise Visitor Center

The chief hazard in the Paradise area is from pumice fall, although unless there is a strong north wind blowing, this would be more of a nuisance than a serious hazard to life. In addition, there is a chance of an avalanche of rock debris from the volcano, or a hot blast of steam.

1. If an eruption starts, or if there are definite warning signs, evacuate people from visitor center, lodge, campground, and picnic ground. Direct people to leave park by way of Stevens Canyon Road unless specifically advised by radio or telephone that Nisqually Entrance Road is passable.

2. If a pumice eruption starts, advise people to stay inside cars or buildings to avoid being hit by rock fragments, or being exposed to toxic or irritating fumes and acids associated with the pumice.

3. If a pumice eruption should begin while a strong northwest wind is blowing, advice should be requested from rangers at Box Canyon and Ohanapecosh Ranger Station concerning hazard from pumice along the Stevens Canyon Road. If pumice fall is so heavy that visibility is poor, people should be directed to stay in the Paradise area.

4. If the Stevens Canyon Road is used, station a ranger with a 2-way radio at Stevens Creek to advise whether the bridge is passable. Flooding in the Paradise River, and condition of bridge over it, probably could be observed directly from Paradise Inn during daylight hours.

5. If both the Nisqually Entrance Road and Stevens Canyon Road are closed, direct people to stay at Paradise Visitor Center, which has emergency stores of food and water. Do not permit people to attempt to walk out of Park, because trail crossings of major rivers may be washed out.

6. If a pumice eruption begins, drinking water should be stored; even if the initial fall of pumice does not affect Paradise Park, the wind could shift and cause pumice to fall there.

Box Canyon

The potential hazards at this locality are from pumice fall and flooding by the Muddy Fork. Even though the deck of the highway bridge at Box Canyon is many tens of feet above the river, the narrow canyon beneath the bridge could become blocked by flood debris, and the river could flow over the visitor-use area.

1. If an eruption begins, direct visitors to leave Park by proceeding southeast and east on highway to Ohanapecosh, thence south to Packwood on State Highway 143, or east to Yakima over White Pass on State Highway 14.

2. If a pumice eruption starts while there is a wind from the northwest, directing people to the east (rather than westward toward the Nisqually River valley) may result in sending them toward an area of heavier pumice fall. Nevertheless, it is believed that direct hazards from the pumice are potentially less dangerous than the threat of mudflows and floods in the Nisqually River valley.

Ohanapecosh Ranger Station and Visitor Center

The hazards at this location are only slight ones--from fall of pumice and from flooding of the Ohanapecosh River. On the basis of the past record, a pumice fall at Ohanapecosh would be a nuisance, rather than a serious hazard to life.

1. If an eruption starts, campers should be directed to leave Park as soon as possible. Direct them to Packwood on State Highway 143.
2. At first sign of flooding in the Ohanapecosh River, immediately move campers to east side of river and direct them to leave Park.
3. Station rangers at Ohanapecosh Entrance Station to prevent visitors from going westbound on Stevens Canyon Road, or northbound toward Cayuse Pass.

Tipsoo Lake

The only hazard is from a pyroclastic eruption. However, the great distance from the volcano would make this a nuisance, rather than a serious menace to life.

1. If an eruption should occur, advise visitors that U.S. Highway 410 probably will be closed northward to Enumclaw and that they should plan to leave via Chinook Pass to Yakima, or, less preferably, to Packwood via State Highway 143 along the Ohanapecosh River valley.
2. Close entrance to Park at Chinook Pass.
3. If a pumice eruption starts, store water as soon as possible for drinking purposes.

White River Ranger Station

The chief hazard at this location is from the fall of pumice; however, because of the distance from the volcano, the pumice probably would be a nuisance rather than a serious menace to life. The ranger station is on a high terrace and thus would be endangered only by extremely high flooding. However, at least twice in the past 10,000 years, mudflows have covered the terrace.

1. If an eruption starts, or if there are definite warning signs, notify Forest Service personnel and people who live on or adjacent to the valley floor downstream that there is a danger from flooding.
2. Station a ranger with a 2-way radio at White River bridge to advise personnel at Yakima Park that the bridge is or is not passable.
3. If a pumice eruption starts, advise State Highway maintenance personnel within Park that they may be needed to keep highway clear.
4. Prepare to direct evacuees from White River Campground and Yakima Park toward Chinook Pass. If an eruption has already started do not direct them northward on U.S. Highway 410 to Enumclaw. The highway is subject to being flooded or washed out at many places downstream.
5. If a pumice eruption starts, store drinking water as soon as possible.
6. Evacuate nonessential personnel (families) to Ohanapecosh Ranger Station.
7. Do not permit visitors to enter the Park.

White River Campground

The specific hazards are floods, mudflows, avalanches of rock debris (like that of 1963 from Little Tahoma Peak), and fall of pumice.

1. If White River floods, or other warning signs of an eruption occur, advise campers to prepare to leave campground as soon as possible.
2. Before sending campers down the campground entrance road in cars, determine whether road is passable (some parts of the road are only a few feet above the river).
3. If entrance road is passable, and White River bridge is intact, send people to White River Ranger Station and Chinook Pass. If White River bridge is not passable, send people to Sunrise Point or Yakima Park by car.
4. If road from campground is not passable and campground is in immediate danger of being flooded, send campers to Yakima Park by foot trail. Advise them to take along blankets, food, and water. Blankets would provide some protection from hot pumice.
5. Campers should be advised to stay under cover during fall of pumice. Fragments of pumice and solid rock several inches in diameter might fall at campground and accumulate to a depth of several inches or more. There may also be a danger from toxic or irritating gases and acids associated with the pumice fall.
6. If a large avalanche occurs that closely approaches the campground, leave the campground with great haste either by car or on foot. Go down entrance road or up the trail toward Yakima Park. A still larger avalanche could occur at any time that might overwhelm the campground.

Yakima Park Ranger Station and Visitor Center

The chief potential hazard at Yakima Park is an eruption of pumice. In addition, visitors could be isolated at Yakima Park if floods made the White River Entrance Road impassable.

1. If an eruption should begin, or if there is a series of signs suggesting that an eruption is about to occur, direct visitors in campgrounds, picnic grounds, and visitor center to prepare to leave immediately.
2. Determine either by personal reconnaissance, or by telephone call to White River Ranger Station or White River Campground, whether White River bridge is intact. If it is, send people by entrance road to Chinook Pass.
3. If entrance road is not passable, advise people to stay in vicinity of visitor center.
4. If pumice begins to fall, advise people to stay inside cars or buildings. Fragments of pumice and hard, heavy rock several inches in diameter could fall and accumulate to a depth of several inches or more. Toxic or irritating gases and acids could accompany the pumice fall.

5. If the pumice fall is very heavy, consider moving to Sunrise Point during a lull in the eruption. That location is 3 miles farther east, and pumice will be both smaller in size and thinner. However, this advantage must be weighted against the disadvantage of the lack of shelter at Sunrise Point.

6. If a pumice fall has started and visitors cannot be evacuated, draw drinking water as soon as possible and store in containers. The water system could become blocked by pumice, and the water could temporarily become highly acidic.

7. Do not attempt to evacuate people by foot trails; trail bridges could be swept away by floods. Wait for helicopter evacuation, or additional instructions.

Carbon River Ranger Station

The hazards here are mudflows and floods down the Carbon River.

1. If notified that an eruption has started, or is imminent, close entrance to visitors.
2. Reconnoiter road from entrance to Ipsut Creek Campground to determine if it is passable.
3. Evacuate campground.
4. Evacuate Ranger Station.
5. Advise residents of valley floor between Park and Fairfax of flood danger.

Ipsut Creek Campground

The hazards are from mudflows and floods down the Carbon River, but there is also a possibility of avalanches of rock debris.

1. If an eruption begins or if the Carbon River starts to flood, instruct campers to prepare to leave campground immediately.
2. When it is known that entrance road is passable, evacuate campers.
3. If road is impassable or if water is coming into campground, evacuate people along Ipsut Creek trail, carrying blankets and food.

Mowich Lake Campground

An eruption of Mount Rainier would be of virtually no danger at Mowich Lake Campground, although a strong southeast wind during a pumice eruption could cause pumice to fall at Mowich Lake. Strong winds from this direction are rare. Campers should be directed to leave the Park by way of the Mowich Lake Road to avoid being isolated in the event the road should be cut off somewhere outside the Park.