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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MUDFLOW HAZARDS ALONG THE TOUTLE AND COWLITZ RIVERS FROM A HYPOTHETICAL FAILURE OF SPIRIT LAKE BLOCKAGE

By Charles H. Swift III and David L. Kresch

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UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

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Tacoma, Washington 98402-4384

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METRIC (SI) CONVERSION FACTORS

Multiply	By	To obtain
cubic yards (yd^3)------------------	0.7646	cubic meters (m^3)
miles (mi)-------------------------	1.609	kilometers (km)
acre-feet (acre-ft)----------------	1233.	cubic meters (m^3)
cubic feet per second (ft^3/s)------	0.02832	cubic meters per second (m^3/s)

MUDFLOW HAZARDS ALONG THE TOUTLE AND COWLITZ RIVERS FROM A HYPOTHETICAL FAILURE OF SPIRIT LAKE BLOCKAGE

By Charles H. Swift III and David L. Kresch

ABSTRACT

The debris avalanche accompanying the May 18, 1980, eruption of Mount St. Helens, in southwestern Washington, buried the former outlet channel of Spirit Lake, located 5 miles north of the volcano, to a depth ranging to 500 feet. Since that time, Spirit Lake has had no natural outlet and its water surface and contents have increased significantly. Recent studies of the debris dam stratigraphy and soil properties, and of erosion on the surface of the blockage, have led to concern that the lake may someday breach through or spill over the top. A study was made by the U.S. Geological Survey (USGS) to determine the extent of inundation that might result downstream in the Toutle and Cowlitz Rivers if a hypothetical breach should occur and generate a mudflow flood of catastrophic proportions.

The effects of a hypothetical breach beginning at a lake level elevation of 3,475 feet and based on geologic and soil properties of the debris dam were determined using a dam-break computer model. Approximately 314,000 acre-feet of stored lake water were released, resulting in a clear-water peak discharge of 530,000 cubic feet per second. It was then assumed that 2.4 billion cubic yards of sediment would be entrained in the flow between Spirit Lake and Camp Baker on the North Fork Toutle River. The effects of this sediment entrainment were added to the clear-water discharge hydrograph to generate a hypothetical mudflow hydrograph at Camp Baker. The peak discharge of this mudflow hydrograph was 2.65 million cubic feet per second. The assumed sediment concentration was 65 percent by volume.

The mudflow was then routed downstream along the Toutle and Cowlitz Rivers in further computer simulations. These simulations indicated attenuation of the peak discharge to 1.53 million cubic feet per second downstream of the confluence with the South Fork Toutle River, due primarily to overflow into Silver Lake; a reduction to 1.38 million cubic feet per second at the mouth of the Toutle River, due primarily to overflow into Salmon Creek, a tributary to the Cowlitz River near Toledo; and attenuation to 1.14 million cubic feet per second in the Cowlitz River just downstream of the Toutle River mouth, due to travel of the flow both upstream and downstream in the Cowlitz River. Elevations determined by the hydraulic routing of the mudflow were used to prepare inundation maps, indicating depths of inundation to be about 60 feet at Castle Rock and Lexington; 30-40 feet at Toutle, Toutle Lake, Kelso, and Longview; and 15-20 feet at Toledo. For the debris dam failure scenario assumed in this analysis the time between transmission of a failure alert by the USGS-NWS telemetry system and the start of mudflow flooding at downstream communities is estimated to be 3 hours at Kid Valley, 5 hours at Silver Lake, 10 hours at Castle Rock, 14 hours at Toledo and Lexington, and 16 hours at Kelso-Longview.

INTRODUCTION

The explosive May 18, 1980, eruption of Mount St. Helens, in southwestern Washington, deposited approximately 3.9 billion cubic yards of rock, ice, vegetation, ash, and dirt in the upstream 18 miles of the North Fork Toutle River valley (Meyer and Carpenter, oral commun., 1982). The former outlet channel of Spirit Lake was buried by debris ranging in depth to 500 feet by this blockage, thus leaving the lake without an outlet. The contents of Spirit Lake have increased from 123,000 acre-feet shortly after the May 18 eruption to 275,000 acre-feet in December 1982. If the lake level were to rise to the existing top of the debris dam, its contents would be 500,000 acre-feet.

To mitigate the likelihood of a breakout of the lake, the U.S. Army Corps of Engineers (COE) began pumping water from Spirit Lake at a rate of approximately 170 cubic feet per second in November 1982, and a month later increased the pumpage to 180 cubic feet per second. With normal precipitation the goal of the pumping operation is to stabilize the lake level at an average elevation of 3,462 feet, which corresponds to a lake volume of 275,000 acre-feet. However, in the event of a 100-year seasonal inflow to Spirit Lake the COE expects that it can prevent the lake level and corresponding contents from exceeding 3,475 feet and 314,000 acre-feet, respectively. Greater-than-normal precipitation, failure of the pumping system, and/or addition of material to Spirit Lake from an eruptive event could cause the lake level to exceed elevation 3,475. In an extreme case the debris dam could fail, releasing a flood of water into the upper reaches of the Toutle River System.

This report identifies mudflow flood hazards associated with a breach of the Spirit Lake debris blockage starting at a lake elevation of 3,475 feet. The report presents the results of an analysis of what would occur downstream if the blockage were to fail (according to a particular scenario) and if the ensuing flood were then to incorporate sediment to form a mudflow. Observations since the May 18 eruption indicate that in the event of a large flood a mudflow is likely to result.

This report is not a prediction that the Spirit Lake debris dam will fail or that a mudflow flood will result if the blockage fails. There are many uncertainties about the structure of the debris dam; the possibility of a failure and subsequent mudflow cannot presently be ruled out. For the purpose of emergency preparedness, it is prudent to examine the possible consequence of a rapid failure and the development of a mudflow flood under a set of conditions which approximates a plausible catastrophic failure. These conditions are outlined below and described in greater detail in later sections.

A dam-break model was used to calculate the flow of water from Spirit Lake following an assumed failure of the debris dam by piping. The results of this calculation consisted of a "clear-water" hydrograph describing outflow at the point of failure as a function of time. This hydrograph was in turn used to estimate a mudflow hydrograph at Camp Baker, 18 miles downstream from the lake, at the toe of the debris pile. The mudflow hydrograph, giving the discharge of water and sediment as a function of time at Camp Baker, was generated by assuming that 2.4 billion cubic yards of sediment would be added to the water as it moved downstream. The flow rates indicated by the lake outflow hydrograph were adjusted to account for this addition of sediment, to obtain the mudflow hydrograph at Camp Baker.

The estimated mudflow hydrograph at Camp Baker was then used as the input in a mudflow-routing model, which calculated flow rate and surface elevation as a function of time at various points downstream to the mouth of the Toutle River. In a second application of the mudflow-routing model the input from the Toutle River was routed both upstream and downstream on the Cowlitz River.

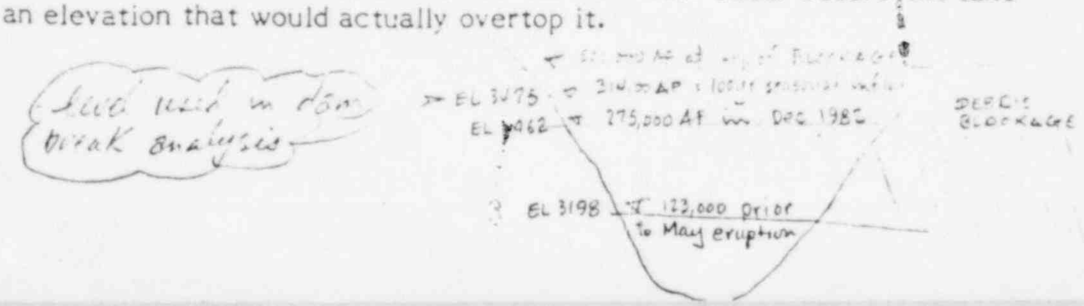
It is important to note that, had a different mechanism of dam failure been postulated, a different lake outflow hydrograph would have been obtained, and this in turn would have altered downstream results. It is also important to note that the results are dependent on the assumption that 2.4 billion cubic yards of sediment would be entrained in the flow. Had a different assumption been made with regard to sediment load, the results would have differed.

This report was prepared at the request of the Federal Emergency Management Agency (FEMA) to identify the specific flood-hazard areas associated with a catastrophic mudflow flood, if it should occur.

DAM-BREAK MODEL

A Spirit Lake outflow hydrograph was determined by the personnel of the U.S. National Weather Service (NWS) (Dan Fread, oral commun., 1982) using a dam-break computer model that utilizes the geologic and soil properties of the materials through which a breach develops. The NWS dam-break model computes a "clear-water" failure hydrograph; sediment in sufficient concentrations to form a mudflow is not considered. In the model an assumption must be made as to the nature of the failure process.

The nature of the debris deposits suggests that, were failure to occur, piping might be a plausible mechanism for such a failure. Easily erodible deposits underlay the lowest points on the crest of the blockage. Steep-walled channels up to 60-feet deep have been eroded into these deposits and are working headward toward the crest of the blockage (Meyer and Carpenter, oral commun., 1982). Preliminary studies of the stratigraphy and physical soil properties of the debris materials (Glicken, Meyer, and Alvord, written commun., 1982) show that the materials in the upper part of the debris dam are comparatively light in weight and porous and consequently may not serve as an effective barrier to the lake waters. Therefore, it is conceivable that a failure of the barrier could occur before the lake would reach an elevation that would actually overtop it.



Once a failure mechanism is assumed the model then simulates the development of the breakout, generating an outflow hydrograph. The shape and peak discharge of a dam-breach outflow hydrograph (flood wave) depends on how quickly and to what size the breach enlarges, both of which are functions of the degree of resistance to erosion along the flow path. Geologic and soil properties of the Spirit Lake blockage materials were determined by personnel of the USGS on the basis of field surveys and laboratory analysis and were then furnished to the NWS for inclusion in the computer model. The median grain size of the deposits utilized into the model were:

Elevation	Median grain size (mm)
Above 3,527	0.06
3,518-3,527	.25
3,450-3,518	.50
below 3,450	7.00

The outflow hydrograph used was based upon a simulation in which piping was the assumed failure process; similar outflow hydrographs were obtained in simulations in which failure occurred through overtopping and subsequent erosion. A failure by liquefaction of the deposits by an earthquake was not analyzed and might produce a larger breach and peak flow; however, the impact of the larger peak on centers of population would probably be little different from that of the mudflow analyzed in this report.

MUDFLOW HYDROGRAPH

Observations of breakouts from much smaller lakes downstream of Spirit Lake indicate that as the water travels downstream, large quantities of sediment are entrained in the flow. If an adequate supply of sediment is readily available, the flow can develop into a mudflow. A mudflow is a flowing water-sediment mixture in which the sediment volume constitutes between 40 and 80 percent of the total volume of the mixture. When sediment volume reaches approximately 80 percent of the total volume, the mixture stiffens and ceases to move. When sediment volume is less than 40 percent, the fluid mixture exhibits the hydraulic characteristics of water.

Of the 3.9 billion cubic yards of material deposited in the upper North Fork Toutle River valley, about 2.6 billion cubic yards are estimated to be readily available along potential flow paths of a Spirit Lake breakout flood. For the simulated flood conditions, the lake volume at the time of failure is 314,000 acre-feet; to attain a mudflow-sediment concentration of 65 percent by volume, it would be necessary to incorporate approximately 2.4 billion cubic yards of sediment in this volume of water. Because more than that volume of sediment is readily available downstream, the development of a mudflow is entirely possible. A hypothetical mudflow hydrograph in the vicinity of Camp Baker, located 18 miles downstream from Spirit Lake, was estimated by adjusting the outflow hydrograph obtained from the NWS dam-break model to account for the effects of sediment entrained in the water. It was assumed that the only changes in the outflow hydrograph between Spirit Lake and Camp Baker would be increases in stage and discharge associated with the incorporation of sediment.

The adjustments to the outflow hydrograph were made on the basis of the volume, physical characteristics, and water content of the downstream debris, and an estimated peak flow travel time. The concentration of sediment in the water was assumed to be 65 percent by volume, which is a value observed in many mudflows. The porosity and saturation of the downstream debris deposits was assumed to be 32 percent and 50 percent, respectively, on the basis of field observations. The instantaneous peak discharge of this mudflow was 2.65 million cubic feet per second at Camp Baker.

MUDFLOW ROUTING

The estimated mudflow hydrograph at Camp Baker was taken as the input to a second simulation using a model developed by Land (1981), in which the mudflow was routed downstream along reaches of the Toutle and Cowlitz Rivers to obtain estimates of the elevation and extent of flooding. To simulate the hydraulics of a mudflow, effective friction coefficients computed from a uniform mudflow equation (Chen, oral commun., 1982) were substituted for clear-water friction coefficients.

As the hydrograph was routed downstream its peak discharge decreased or became attenuated. Minor attenuation occurred along all river reaches through which the mudflow was routed due to temporary storage of flow in and adjacent to the river channels. Major or abrupt occurrences of attenuation were (1) at the confluence of the North and South Forks of the Toutle River, (2) along the Toutle River near Tower, and (3) at the mouth of the Toutle River.

The peak discharge decreased from 2.55 million cubic feet per second 5 miles upstream from the confluence of the North and South Forks of the Toutle River to 1.53 million cubic feet per second immediately downstream from the confluence. This large attenuation was caused by the temporary storage of flow across the wide flood plain at the confluence and within Silver Lake, which has a capacity for the storage of several hundred thousand acre-feet. Farther downstream along the Toutle River, mudflow elevations in the vicinity of Tower were higher than the drainage divide between the Toutle River and Salmon Creek, a Cowlitz River tributary much smaller than and approximately parallel to the Toutle River, thus indicating overflow into Salmon Creek. A peak discharge of 110,000 cubic feet per second was computed for the overflow into Salmon Creek.

Due to the gentle slope of the Cowlitz River, large portions of Toutle River mudflow entering the Cowlitz River flow upstream temporarily until passage of the peak, thus reducing the peak discharge in the Cowlitz River. Correspondingly, the peak flow in the vicinity of the mouth of the Toutle River decreased from 1.38 million cubic feet per second at the mouth to 1.14 million cubic feet per second immediately downstream in the Cowlitz River. The mudflow was routed downstream in the Cowlitz River with a resulting peak flow of 1.09 million cubic feet per second as it discharged into the Columbia River.

Mudflow depths at any location can be computed as the difference between the computed maximum mudflow elevation and the ground elevation. Typical mudflow depths computed for several communities along the Toutle and Cowlitz Rivers that lie partially or completely within the inundation boundaries are 60 feet at Castle Rock and Lexington; 30 to 40 feet at Toutle, Toutle Lake, Kelso, and Longview; and 15 to 20 feet at Toledo. The depth at the road surface of the Interstate 5 bridge crossing of the Toutle River is 40 feet.

The USGS and NWS have installed a hazard-warning system consisting of three reporting stations on Spirit Lake and two on the channels below the Lake. This system will transmit an alert by satellite and radio telemetry if there is a sudden drop of lake level and/or increase in flow below the lake, equivalent to about 20,000 cubic feet per second. For the particular debris dam failure scenario assumed in this analysis the time between the transmission of the alert and the flooding of downstream communities is approximately as shown below.

Location	Flood arrival (hours)	Peak-flow occurrence (hours)
Spirit Lake (at point of failure)	--	12
Kid valley	3	13
Silver Lake	5	14
Castle Rock	10	17
Toledo	14	19
Lexington	14	19
Kelso-Longview	16	20

The time shown for flood arrival refers to first entry into populated areas. Peak flow times give the interval after the alert at which the flow approximates its maximum value at the given location. If a different debris dam failure scenario were assumed these times could differ.

MUDFLOW INUNDATION MAPS

The mudflow hazard information determined for this report is presented on a set of 10 topographic maps (pls. 1-10) and an index map (fig. 1), prepared from standard 1:24,000 scale U.S. Geological Survey quadrangle base maps. The lateral limits of the mudflow were plotted at river cross-sections on the maps. Inundation boundaries were drawn on the maps by interpolating between the mudflow lateral limits at adjacent cross sections using the topographic contours. Maximum mudflow elevations along its path are shown at several locations by wavy lines that extend between the boundaries of inundation. As shown on the maps the mudflow would severely impact the communities of Toutle, Toutle Lake, Toledo, Lexington, Castle Rock, and the cities of Kelso and Longview.

The mudflow boundaries delineated for this report compare well with those by Scott and Janda (1982) for an ancient mudflow. Their mapping shows the inundation along the North Fork Toutle River, the Toutle River and the Cowlitz River at and upstream from Castle Rock resulting from a mudflow, occurring over 2,000 years ago, that they suggest most likely originated from the breakout of an ancestral Spirit Lake. Although an accurate determination of the peak discharge of that mudflow is not possible, calculations made on the basis of field observations indicate that it was probably in the range of 2-2.5 million cubic feet per second.

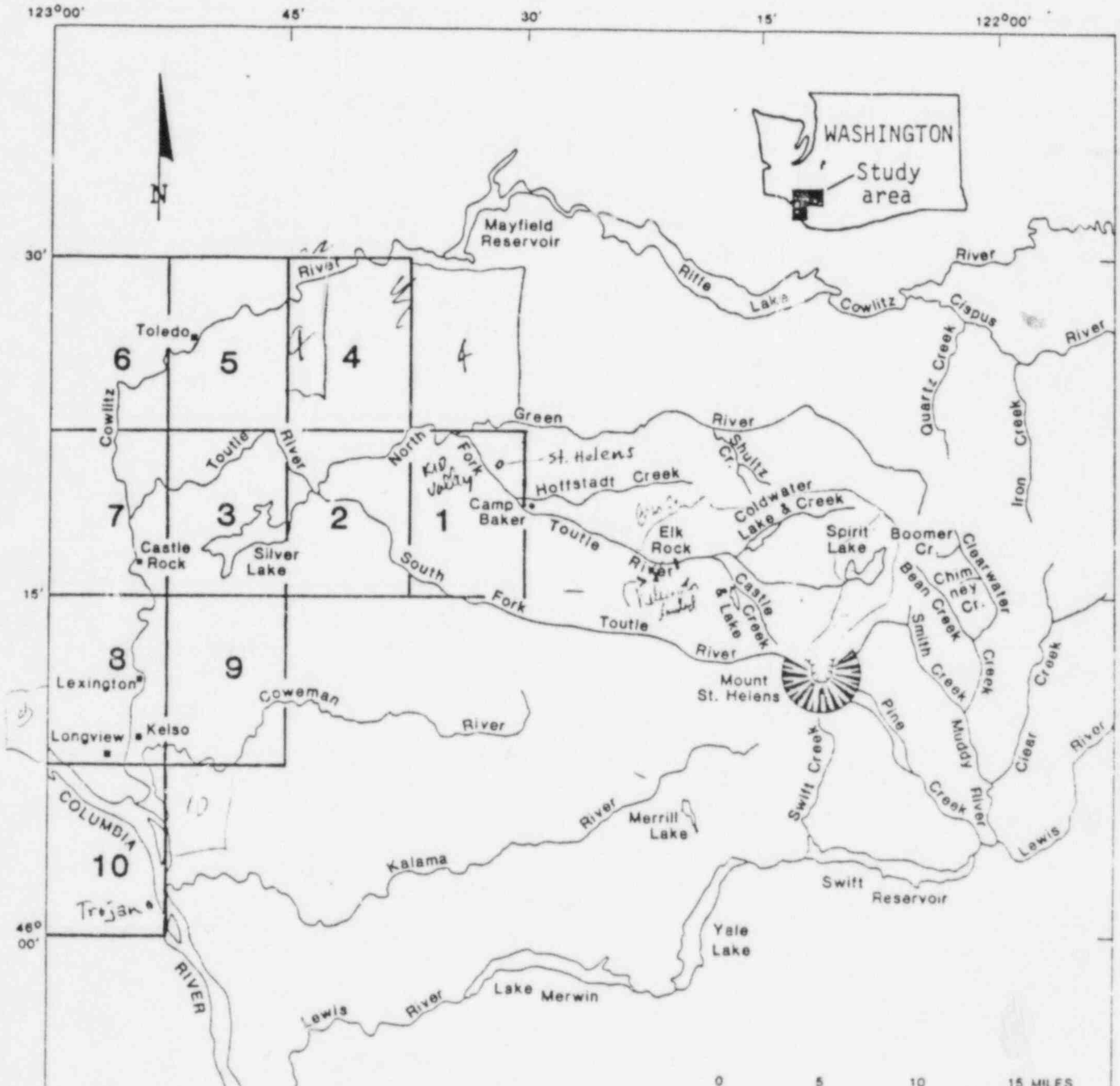


FIGURE 1.--Index map of mudflow inundation maps.

AD P000423

MOUNT ST. HELENS RECOVERY OPERATIONS

by

Robert E. Willis[1]

Introduction

Following the catastrophic eruption of Mount St. Helens, Portland District, Corps of Engineers began perhaps the most unusual recovery operation in the history of the Corps. The purpose of this presentation is to portray, in general terms, the emergency situation that existed and the recovery measures implemented by Portland District.

The Eruption

Mount St. Helens, located in the southwest corner of the state of Washington, has been the most active volcano in the Cascade Range over the last several thousand years. Typically, periods of dormancy have rarely exceeded 200 years. In late March 1980, this picturesque mountain began exhibiting earthquakes and minor steam and ash ejections, signaling a new era of activity for the 123-year dormant volcano. Minor eruptions continued, becoming larger and larger as the weeks passed, resulting in a massive and explosive eruption on Sunday morning, 18 May 1980.

The eruption and blast disgorged an estimated four billion cubic yards (cy) of material, lowering the height of the mountain by more than 1,200 feet and forming a huge crater more than a mile in diameter. The damage, occurring in a 170-degree arc north of the mountain, devastated a 156-square-mile area. The hot gases and the force of the explosion completely destroyed all trees up to seven miles from the mountain, uprooting trees 12 miles out and destroyed other trees as far as 17 miles away.

As shown in figure 1, the blast and resultant mudflows seriously impacted the river basins of the Toutle, Cowlitz, and Columbia Rivers. The debris and mud avalanche left massive deposits in the Toutle River drainage. This deposit extends down the upper reach of the river for a distance of 17 river miles and is over 600 feet thick in places. Volume estimates of the debris avalanche vary from 2.5-3.5 billion cy.

Mudflows that followed carried material which deposited in the Toutle, Cowlitz, and Columbia Rivers. Approximately 50 million cy of sediment was deposited into 21 miles of the Cowlitz River from the mouth of the Toutle downstream, and approximately 45 million cy in the Columbia River near the mouth of the Cowlitz River.

[1]Wildlife Biloligist, U.S. Army Engineer District, Portland

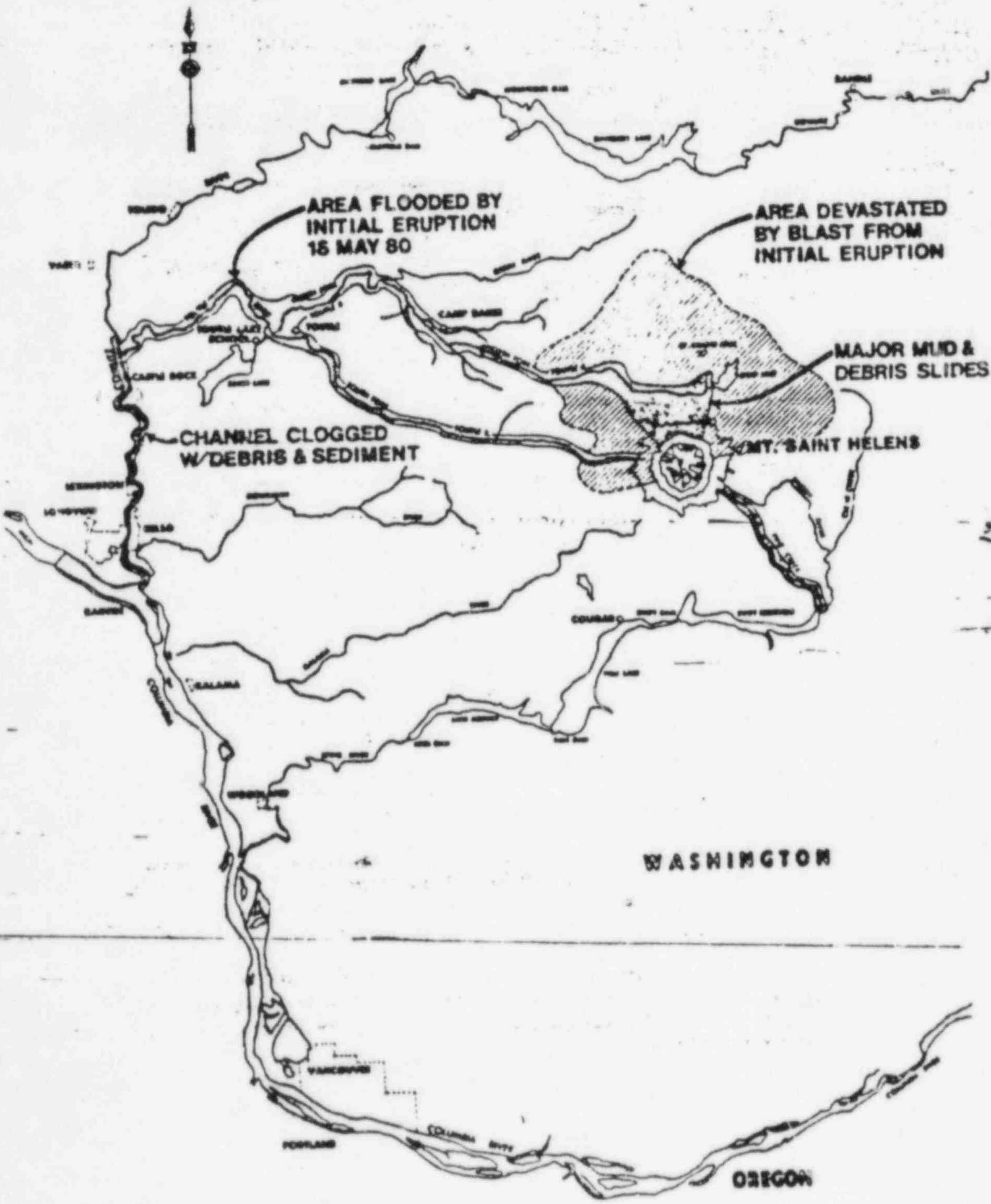


Figure 1 Areas Impacted by the Eruption

COLUMBIA RIVER

The Columbia River navigation channel, from the mouth to Portland, Oregon, is maintained at a 40-foot depth and 600-foot width. The day after the eruption, a vessel ran aground in the middle of this channel. As shown in figure 2, hydrographic surveys revealed a 9-1/2-mile shoal, which had reduced navigation depths to 15 feet. Approximately 14 million of the 45 million cy total infill deposited in the Columbia was in this navigation channel.

On 20 May, a plan for dredging was established (see figure 3) and the Hopper Dredge "Biddle" began work. In 5 days, the three hopper dredges assigned to this emergency had opened an emergency channel that permitted ship passage during high tide "windows" supervised by the U.S. Coast Guard. By 29 May, the channel had been expanded to 25 feet by 200 feet. On 14 June, the last ship of the 31 vessels trapped upstream of the shoal was able to proceed downriver with its cargo of grain. The 14 million cy of infill in the channel project limits were removed generally on schedule, and an unrestricted navigation channel was open to traffic by 30 November 1980. To date, approximately 26 million cy of sediment has been removed to restore and maintain the navigation channel to its pre-eruption state.

COWLITZ RIVER

The 21 miles of the Cowlitz River,from the mouth of the Toutle River downstream to the Columbia River,were impacted severely by the mudflows. Figure 4 illustrates the river profiles of the Cowlitz River before and after the eruption. As shown, natural channel capacities were virtually eliminated by the 50 million cy of infill. Before the ruption, a 76,000-cfs channel was in place. Figure 5 shows the probability of flooding; with even a normal water year, severe flooding would be expected.

Recovery efforts for the Cowlitz River centered around excavating this massive infill to restore its flood carrying capacity to the maximum extent practicable by 1 December 1980. Thirty-three million cubic yards of material was excavated by 1 December, with an addition 23 million cy removed in maintaining this channel, until work was terminated on 30 September 1981.

To remove this 56 million cy of sediment, an intensive and massive effort was required. During the height of operations, the following equipment was in operation: 23 pipeline dredges, 17 tower-type draglines, 52 draglines, 29 backhoes, and 226 hauler-loaders. A total of 4,400 acres were donated as disposal sites by the local landowners. Since an adequate channel would not be in place before the winter rains, flood control storage was obtained from Mossyrock Reservoir on the upper Cowlitz River for the 1980-81 winter.

In addition to the excavation work on the Cowlitz River, the feasibility of other flood protection measures was examined. The construction of levees at certain locations on the Cowlitz were found to be justified. To this end,

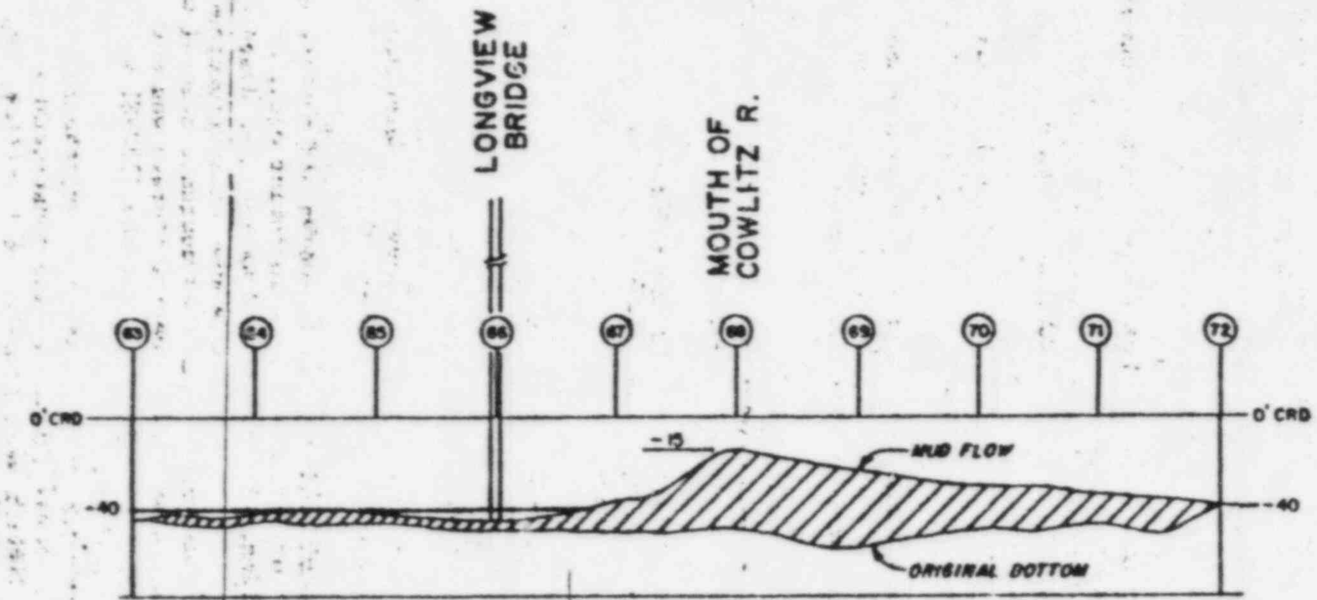


Figure 2

COLUMBIA RIVER LONGITUDINAL PROFILE RM 63-RM 72

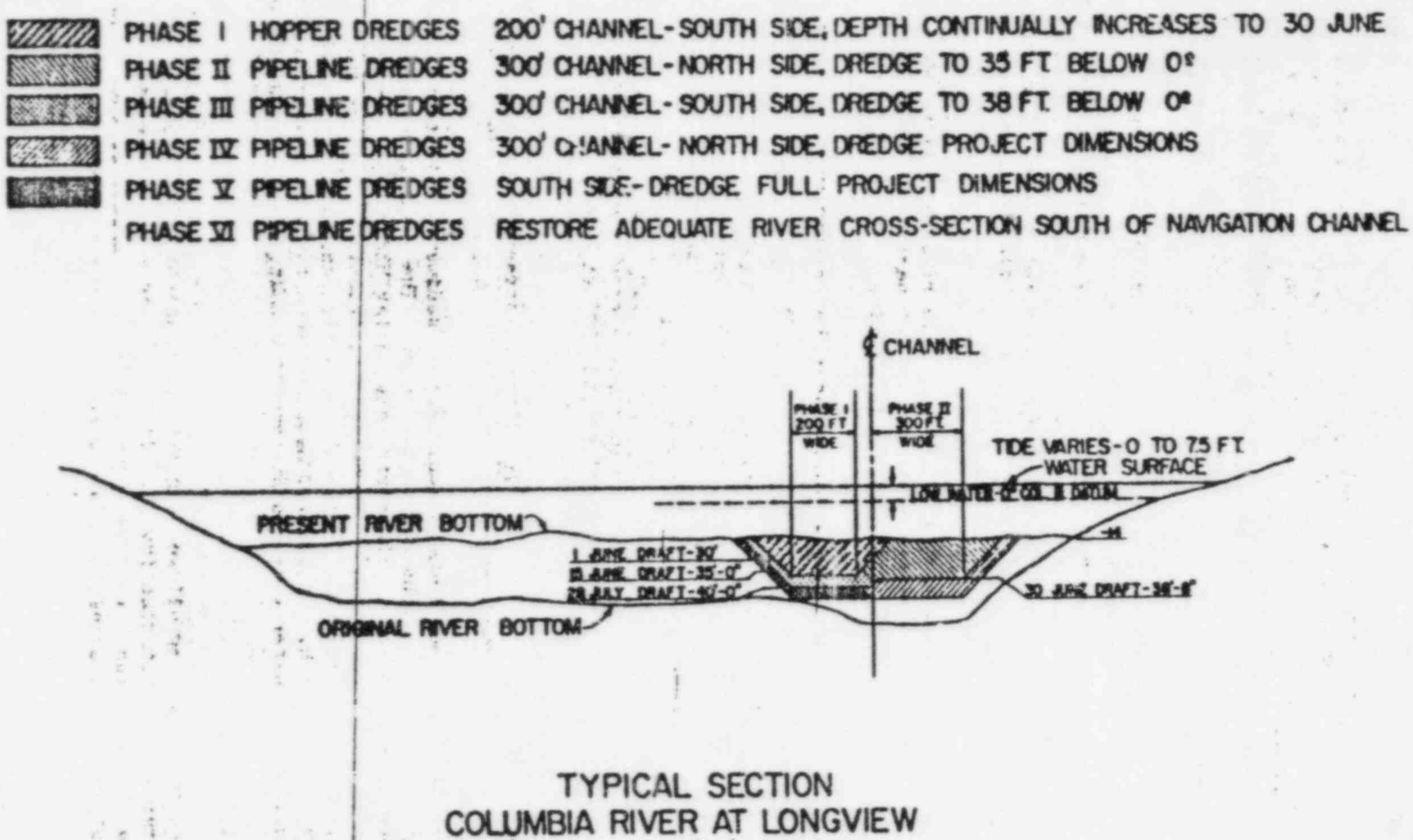


Figure 3 Dredging Plan for the Columbia River

levees providing 500-year flood protection were constructed along the Cowlitz River near the urban areas of Castle Rock, Lexington, Longview, and Kelso; 14,700 feet of existing levee were upgraded and 21,400 feet of new levee were constructed. Bank protection was provided in conjunction with the levees and to control river meandering.

TOUTLE RIVER

Measures implemented in the Toutle River drainage were primarily oriented toward reducing the quantity of sediment eventually depositing in the Cowlitz and Columbia Rivers. Tremendous quantities of sediment continued to erode from the upper watershed mud and avalanche deposits, with the eventual deposition in these lower rivers. Two major techniques were used to reduce this sedimentation: sediment stabilization basins and debris retention structures. The location of these structures is shown in figure 6.

In areas of natural deposition in the Toutle River drainage, eight sediment stabilization basins were excavated. During periods of heavy runoff, sediment was trapped in these basins, therby preventing further infill in the Cowlitz River. During the operation of these structures ending 30 September 1981, 7.5 million cy of sediment was excavated and placed in disposal areas.

Two debris retention structures were constructed: one on the north fork Toutle River and the other on the south fork Toutle River. The debris retention structures, or check dams, resemble earth-fill dams, but they are permeable; they were designed to hold back and impound sediment, which could then be excavated. The north fork structure is 6,000 feet long and 43 feet high, and has a sump capacity of 6 million cy. During the operation of this structure ending 30 September 1981, over 9 million cy of sediment have been removed. The south structure is 600 feet long and 20 feet high, and has a sump capacity of 600,000 cy. During the operation of this structure, approximately 2 million cy of material have been removed. In addition, a fish trap was constructed adjacent to the south fork debris retention structure to trap anadromous fish impeded by this structure.

The debris avalanche, besides contributing sediments, created another problem where recovery operations became necessary. The massive mudfill deposited in the upper 14 miles of the north fork valley had blocked a number of streams, creating ponds and lakes. To prevent catastrophic failure of the debris plugs creating certain of these impoundments, outlet channels were needed at four of the larger ponds. Structural measures were taken to reinforce the outlet channels at Coldwater Lake and South Castle Lake, the larger of these lakes.

Miscellaneous

Within the timeframe allowed for this presentation, it is impossible to detail the myriad of activities involved in these recovery operations. Normal planning and design had to be accomplished at an expedited rate. An example of this expedited schedule is the rate at which contracts were awarded. On

COWLITZ RIVER PROFILE
(BASED ON FLOWS AT CASTLE ROCK)

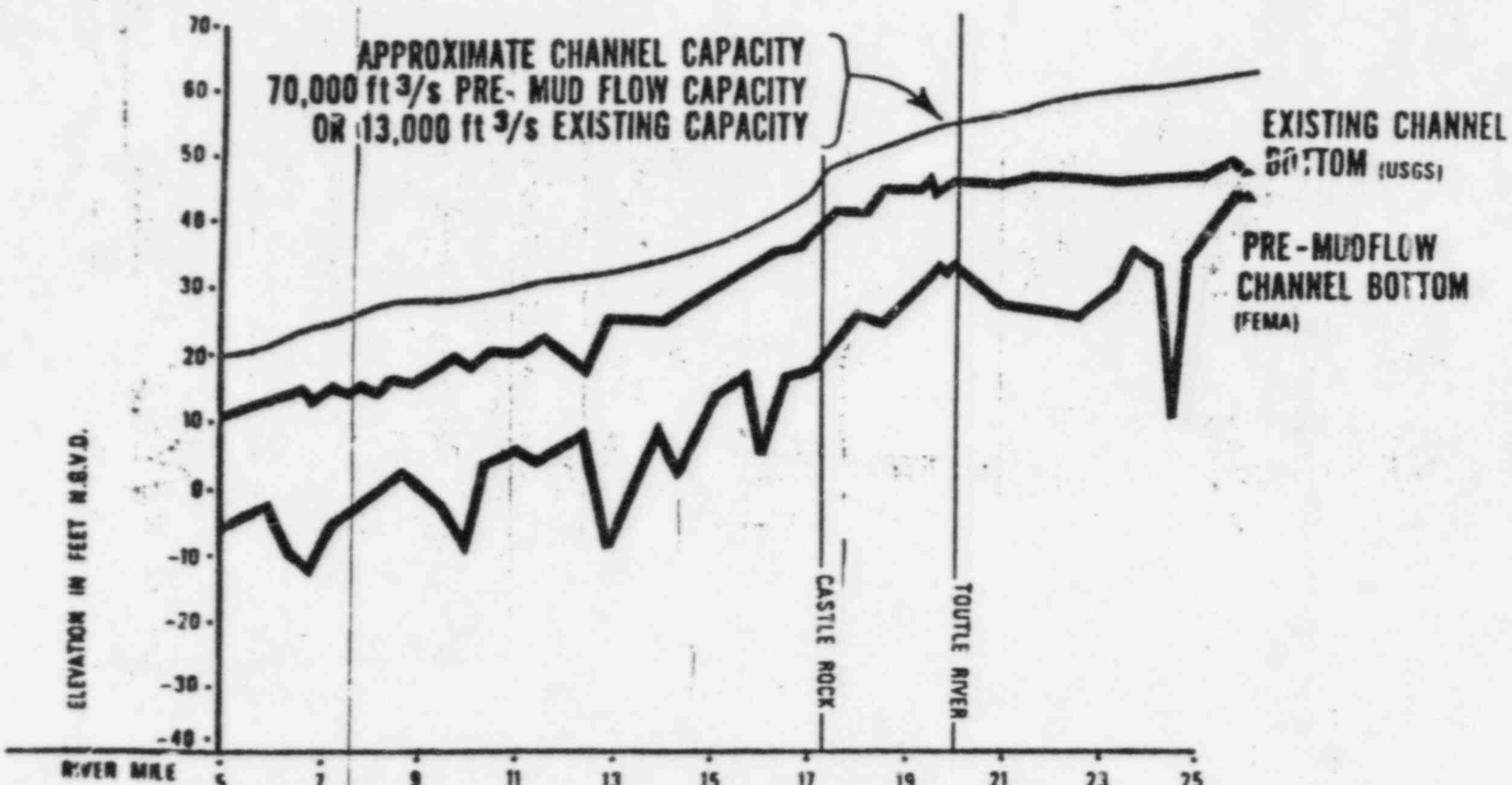


Figure 4 Impact of the Mudflows on the Cowlitz River

COWLITZ RIVER RUN OFF —
COWLITZ RIVER AT CASTLE ROCK

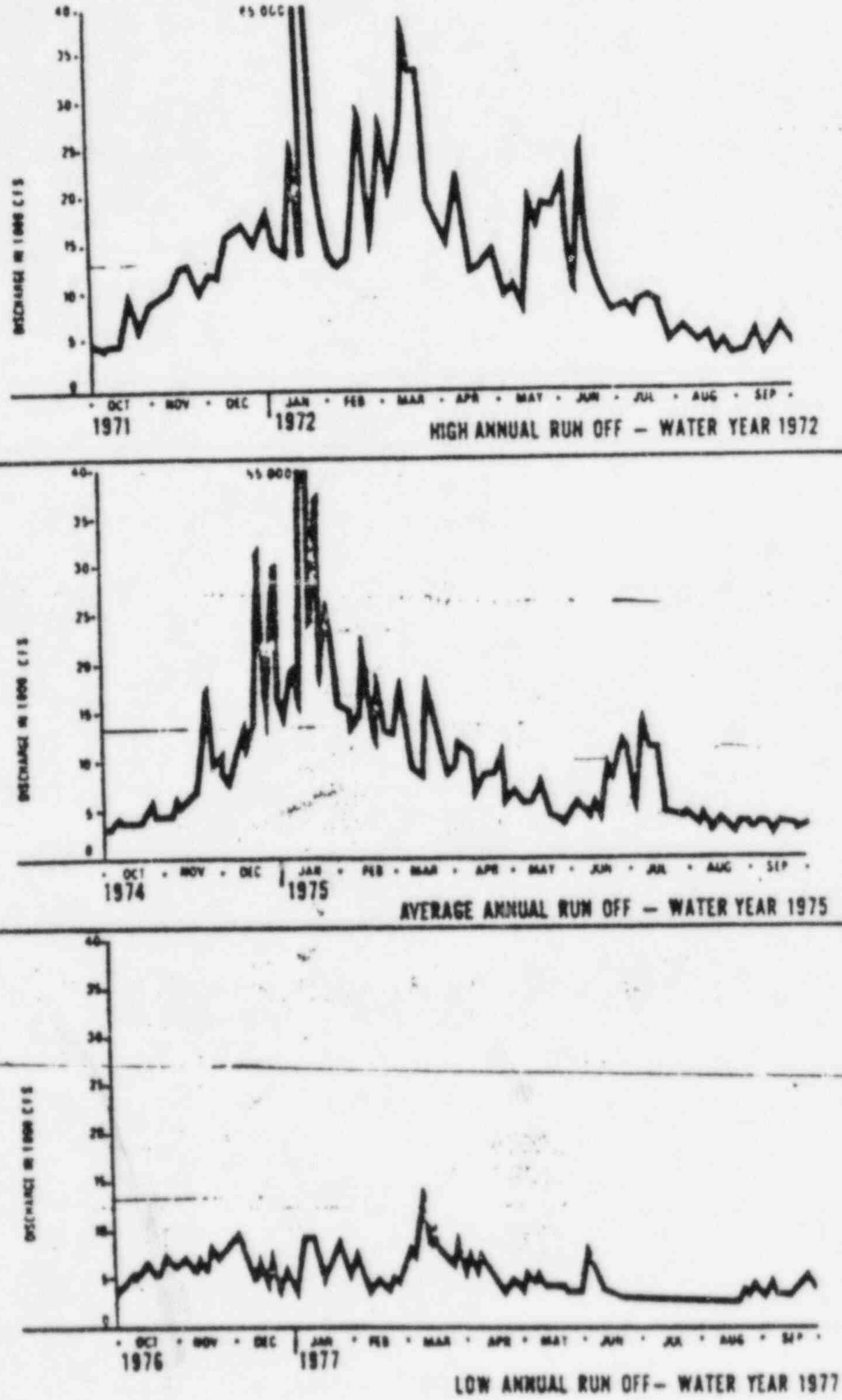


Figure 5 Potential for Flooding on the Cowlitz River

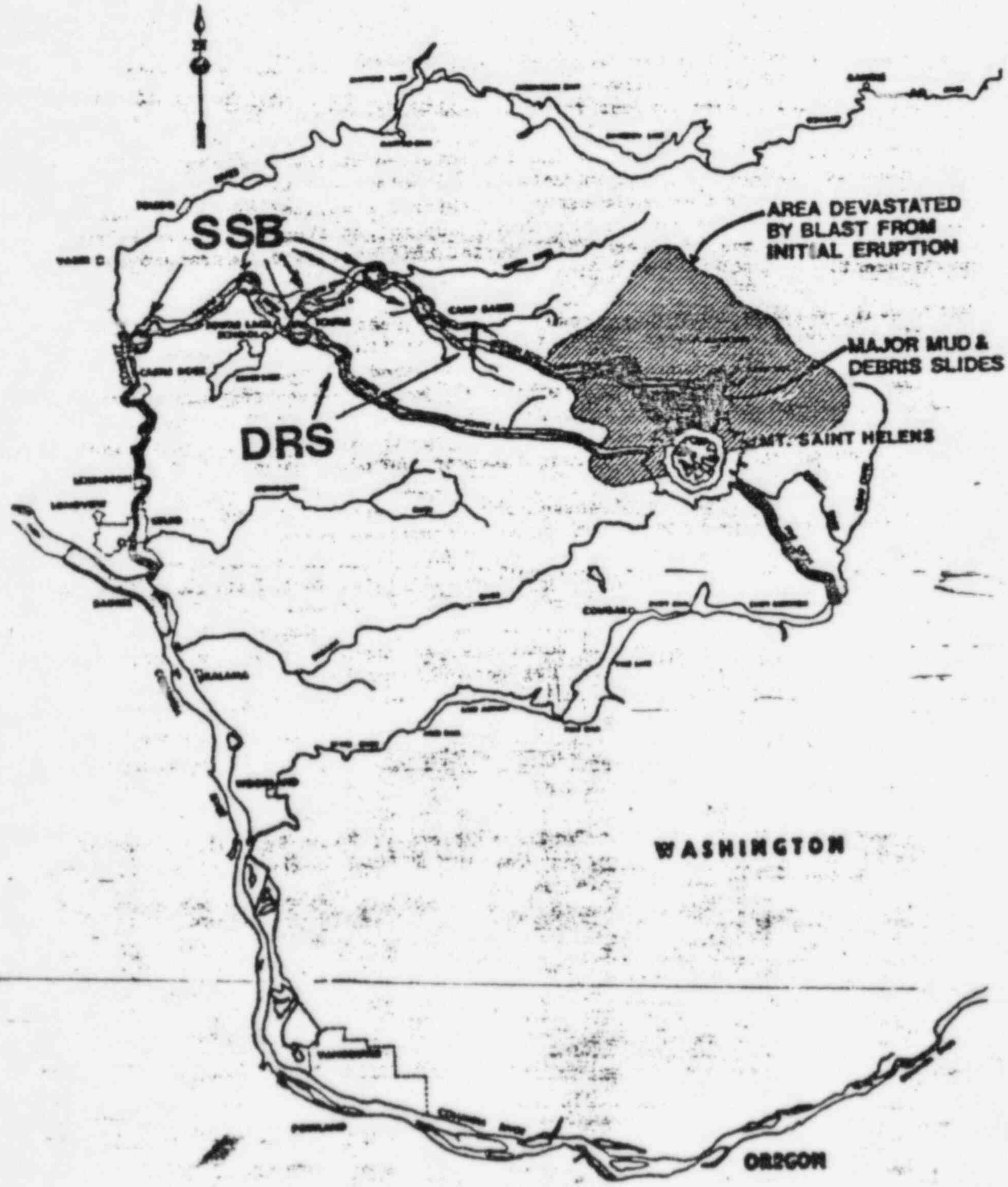


Figure 6 Location of Sediment Stabilization Basins (SSB) and Debris Retaining Structures (DRS)

30 June, over 500 contractors were called to notify them that a pre-bid meeting was to be held tomorrow, 1 July. The next day, 300 contractors from across the country were present for this pre-bid meeting.

Environmental coordination and evaluation occurred at the same rapid pace as the other activities. An environmental impact statement was prepared on an expedited schedule and an environmental taskforce comprised of Federal and State resource agencies was formed; this group met at frequent intervals to insure reasonable measures were taken during this operation to protect the environment.

Water quality evaluations were conducted in conjunction with other environmental assessment and monitoring activities. At first, the major water quality concern was to determine if the ash created any unusual water quality problem beyond the unusually high turbidity. Water quality evaluations continued to determine the effects of the debris retaining structures on the water quality of the Toutle River. But, perhaps the most unusual water quality investigations were associated with the newly formed lakes in the blast zone.

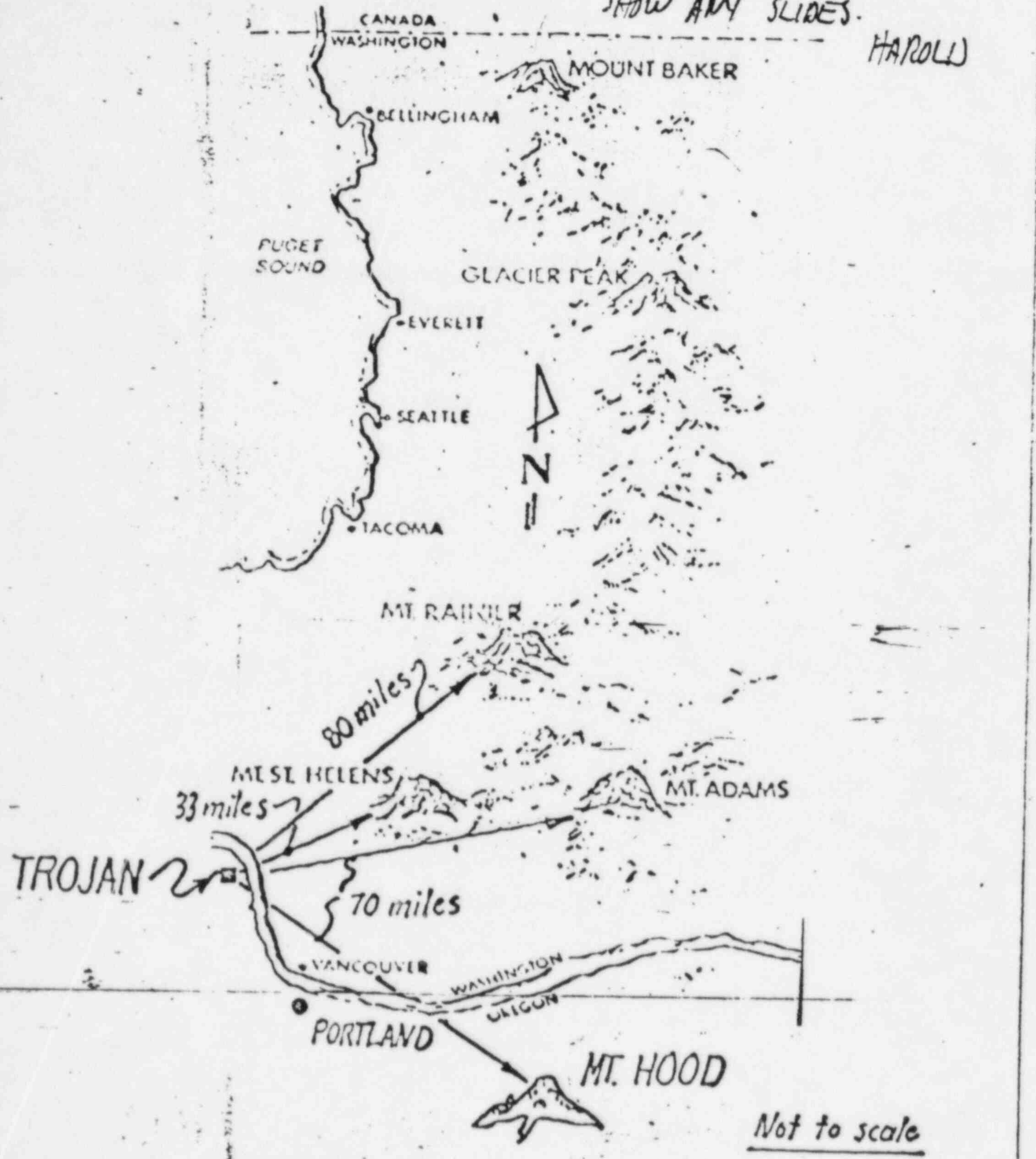
Water quality investigations of these Lahar lakes were conducted in conjunction with evaluations to provide outlet channels for these lakes. Earlier scientific reports indicated that water currently in these lakes was extremely poor in quality, and may be contaminated with pathogenic bacteria and chemical substances. Since a number of downstream communities rely on river water for their drinking water supplies, we commissioned followup water quality studies. In these studies, it was found that massive quantities of organic carbon, sulfur, and metals were loaded into the lakes. Heterotrophic microbial processes, stimulated both by elevated nutrient concentrations and temperature, rapidly consumed the available dissolved oxygen.

This concludes my presentation on Portland District, Mount St. Helens recovery operations. I hope this presentation provided an idea of the complex activities that were necessary in meeting this emergency.

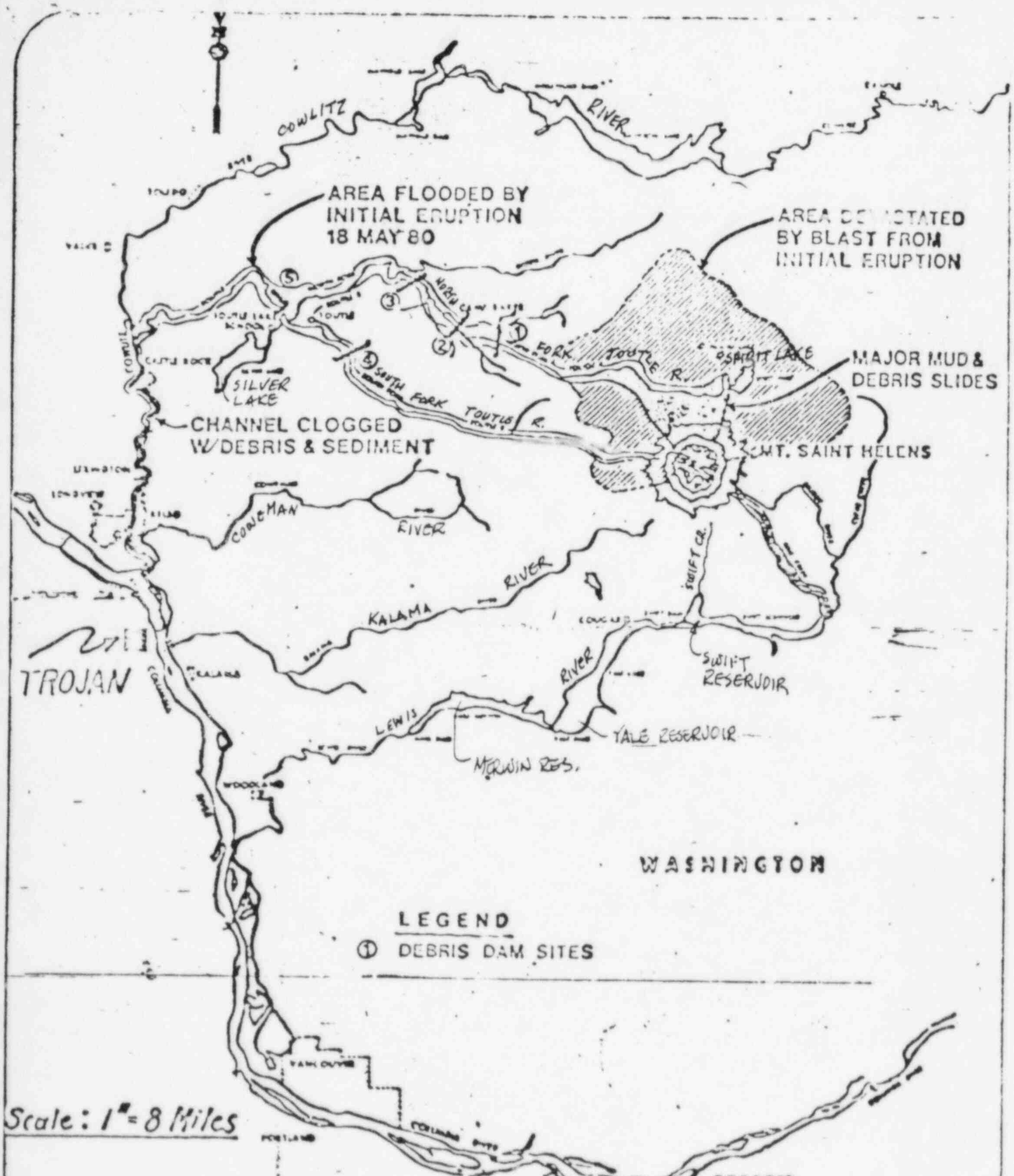
SD-344

BILL: THESE ARE THE VIEW-GRAPHS I INTEND TO USE. I'LL NOT SHOW ANY SLIDES.

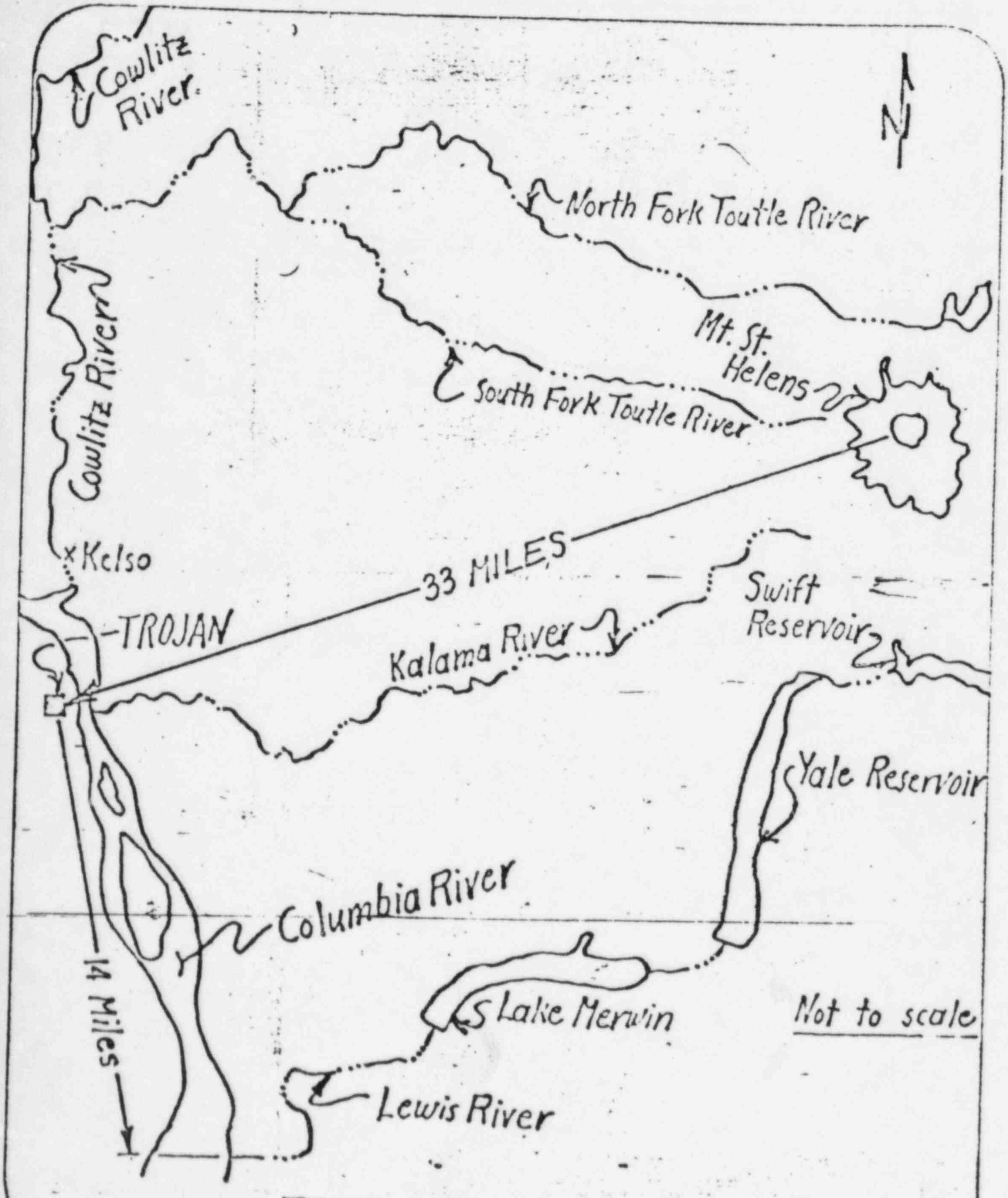
HAROLD



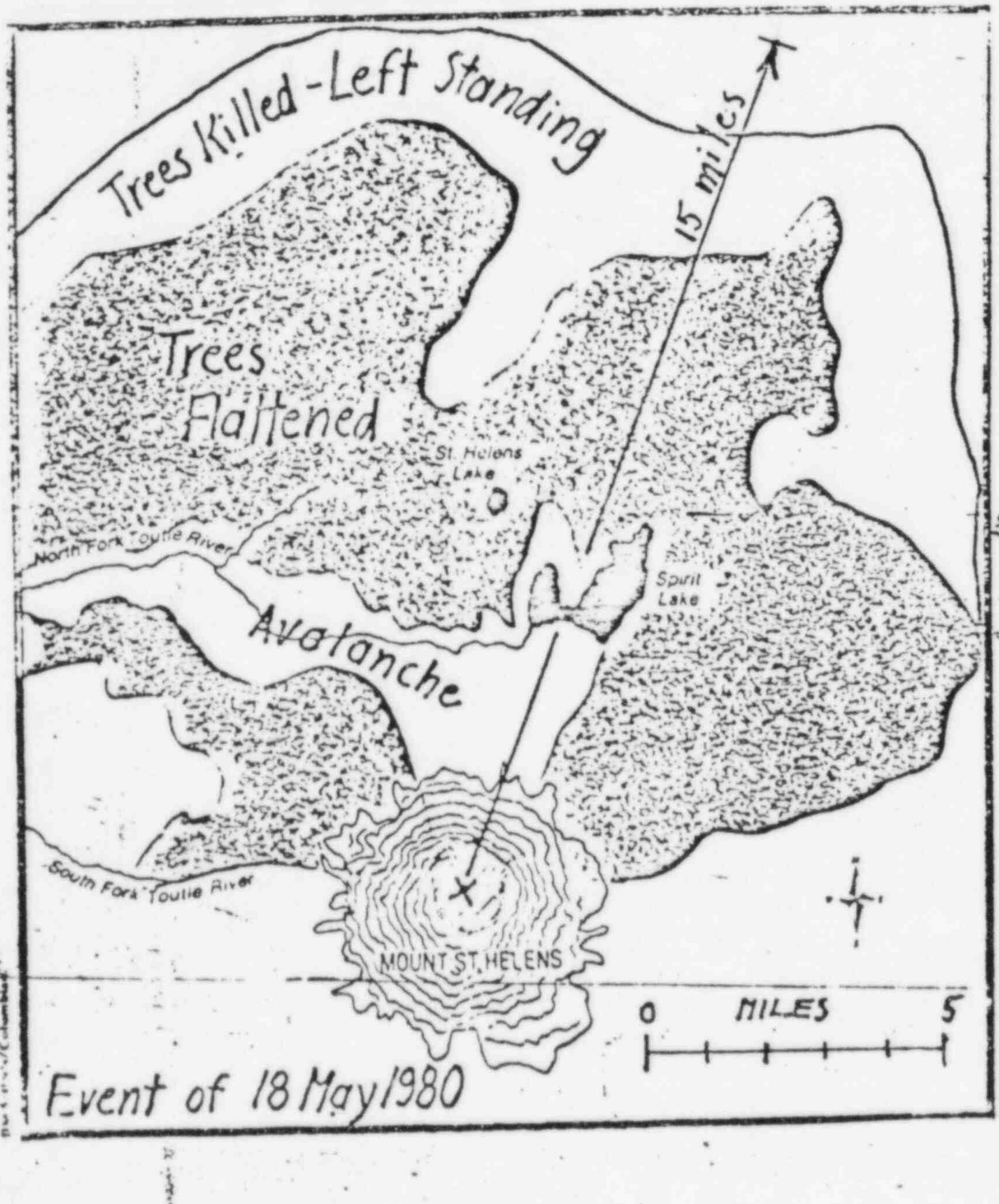
TROJAN-CASCADE VOLCANO RELATIONSHIP

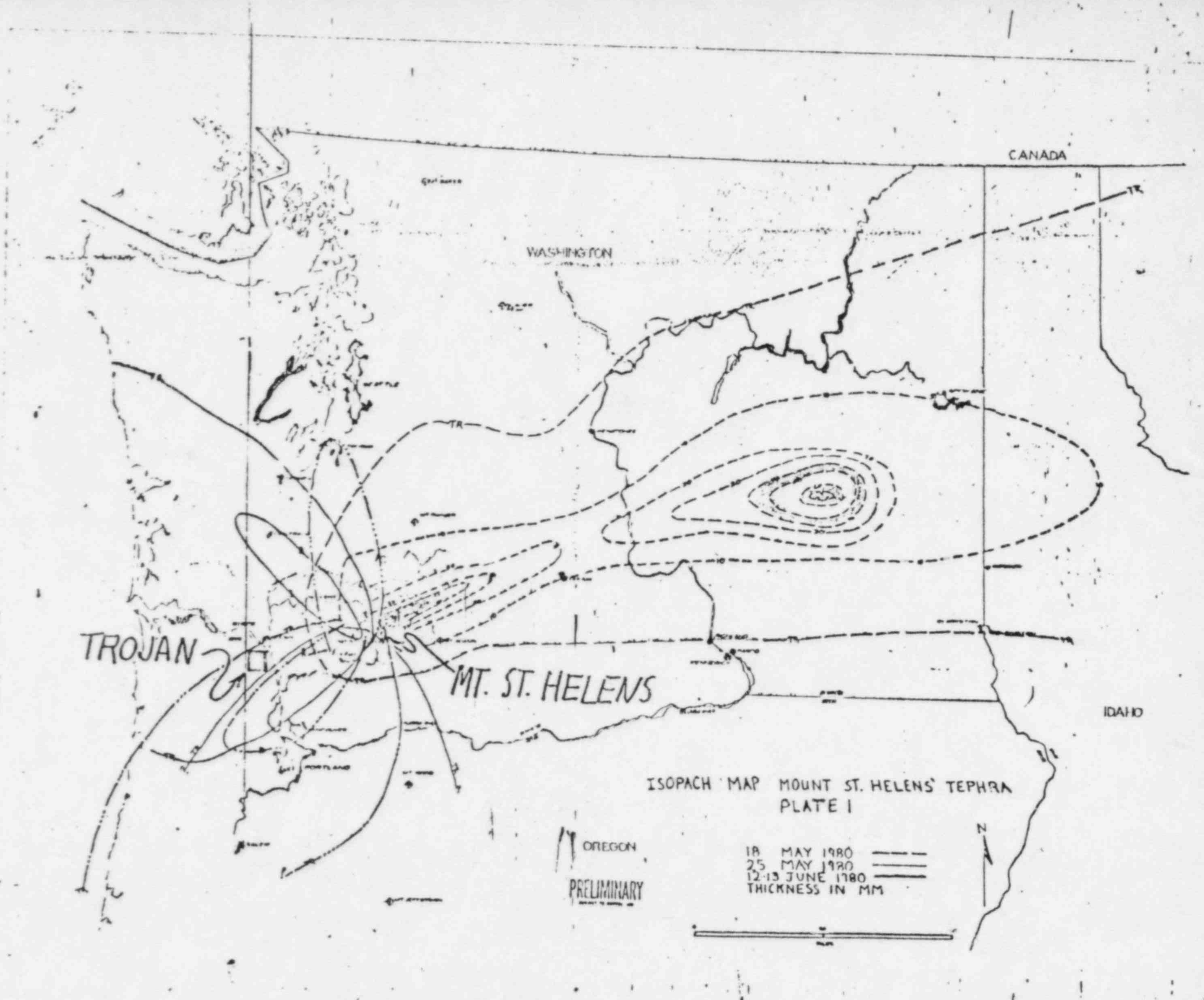


TROJAN-PORTLAND-MT. ST. HELENS AREA



TROJAN-MT. ST. HELENS VICINITY


Trees Killed - Left Standing
15 miles
Trees Flattened
St. Helens Lake
North Fork Toutle River
Spirit Lake
Avalanche
South Fork Toutle River
MOUNT ST. HELENS
0 MILES 5
Event of 18 May 1980


CANADA
WASHINGTON
IDAHO
OREGON
TROJAN
MT. ST. HELENS
ISOPACH MAP MOUNT ST. HELENS' TEPHRA
PLATE I
18 MAY 1980
25 MAY 1980
12-13 JUNE 1980
THICKNESS IN MM
PRELIMINARY
N