FLOOD HAZARDS IN THE SEATTLE-TACOMA URBAN COMPLEX AND ADJACENT AREAS, WASHINGTON

BY

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INTRODUCTION

Floods are natural hazards that have complicated man's land-use planning for as long as we have had a history. Although flood hazards are a continuing danger, the year-to-year threat cannot be accurately predicted. Also, on any one stream, the time since the last destructive flood might be so long that most people now living near the stream have not experienced such a flood. Because of the unpredictability and common infrequency of disastrous flooding, or out of ignorance about the danger, or perhaps because of an urge to gamble, man tends to focus his attention on only the advantages of the flood-prone areas, rather than the risk due to the occasional major flood.

The purposes of this report are to: (1) briefly describe flood hazards in this region, including some that may be unique to the Puget Sound basin, (2) indicate the parts of the area for which flood-hazard data are available, and (3) list the main sources of hydrologic information that is useful for flood-hazard analysis in conjunction with long-range planning. This map-type report is one of a series being prepared by the U.S. Geological Survey to present basic environmental information and interpretations to assist land-use planning in the Puget Sound region.

CAUSES AND ANALYSIS OF FLOODING

Floods are natural recurring events. By far the most common type of flooding in the Puget Sound basin is that caused by excessive runoff from storm precipitation, often augmented by melting of snow. This is the type of flooding to which most of the existing flood-hazard data pertain. However, the unique setting of the Puget Sound lowland creates the possibility of other types of flooding which also should be considered in long-range planning, and which are described briefly below. These include flooding in coastal areas by sea waves, flooding by streams that drain glaciers or volcanic mountains as a result of glacial and (or) volcanic processes, and floods related to other catastrophic events (landslides, earthquakes, earth faulting), especially if they affect lakes or manmade dams or reservoirs.

Runoff and Snowmelt

The strip of flat land, or floodplain, along a stream is part of the high-water channel; occasional reoccupancy of it by the stream is to be expected. Man is attracted to the floodplain by its obvious advantages--the flat land, desirability for transportation routes, access to water and, in this region, the best agricultural soils. Once established on the floodplain, man has characteristically tried to control the damages from flooding by means of dikes, dams, reservoirs, and other flood-control works. Often, these flood-control measures successfully reduce damage from the small to moderate floods and, in so doing, are incentives for additional development on the floodplain. Thus, when a flood occurs that is greater than the capacity of the flood-control works, losses are much greater than if development had been limited by periodic small-scale flooding. The inundation of the floodplain that results from rapid runoff of storm precipitation or snowmelt is the only type of flood that is generally considered in land-use planning in this region and the only type for which patterns of recurrence commonly are derived. Within the Puget Sound region, troublesome floods have occurred in the wintertime, resulting mainly from rapid runoff of rainfall, and also in the spring, largely caused by the rapid melting of snow. The most damaging floods have occurred when intense storms drop warm rains onto saturated snow that is already near the melting point.

The relative flood stages of a typical, unregulated stream are shown diagrammatically in figure 1. The stream channel is shaped principally by the more frequent moderate flood flows and is large enough to accommodate those. Overflow of the floodplain takes care of the water of the less frequent, larger floods that cannot be carried within the channel. As the bottom sketch (A) of figure 1 shows, most of the time less than half the channel is occupied by water. Considerable rain or snowmelt is required to produce enough surface runoff to fill the channel to the top of the banks and cause the river to flow onto the floodplain. In a normal stream, unregulated by the works of man, such bankfull flow might be expected on the average of about once every 2 years (fig. 1A).

As the floodwaters rise and spread farther across the floodplain, increasingly larger floodflows can be accommodated with only small additional rises in water levels. Accordingly, a flood having a recurrence interval of 100 years (fig. 1D) may not inundate much more land than a flood of 50-year recurrence interval (fig. 1C).

It is important to note that flood flows may be partly accommodated by a natural scouring and deepening of the channel by the flood water (fig. 1, A-D). As the flood diminishes, the stream drops enough of its sediment load to restore its channel to roughly the preflood carrying capacity.

The flood flows at various frequencies of recurrence are determined from streamflow records within the drainage basin, from historical flood heights, and by correlation of flood data from stream basins where records are available to similar basins for which no records exist. Also, for places where weather-station data may be available for periods longer than the streamflow record, the magnitude of flooding may be estimated from the amount of runoff likely to be produced by a storm of a certain frequency, or from the most intense foreseeable storm.

The extent of flooding (inundated land) for various flood flows might be determined from historical evidence (high-water marks, observations of residents), or estimated by indirect methods that may include surveying the channel dimensions and slope and then mathematically "routing" floods of various magnitudes through the channel system.

Both the flood heights and extent of flooding may be increased by obstructions to flow, such as ice jams, debris jams, and the encroachment of man's works into the flood channel.

In the area of this map, sufficient streamflow records have been obtained by the U.S. Geological Survey, in cooperation with the State of Washington and various other agencies, to provide reliable flood-frequency estimates for nearly 70 streams at about 90 sites, which are shown on the map. In addition, regional analyses of the flood-flow records and of natural features that control the flows have produced methods for estimating the magnitude and frequency of floods at any site on a natural (unregulated) stream in the region (see "References", Cummans and others, 1974).

One step in the statistical analysis of floods is illustrated by figure 2, which utilizes records of the yearly peak discharge or flow of the Snoqualmie River past a measurement site during a 43-year period, plotted on a special graph to indicate recurrence interval of the various flood flows. This analysis indicates, for example, that flood flows as great as about 65,000 ft^3/s (cubic feet per second) or about 1,850 m^3/s (cubic metres per second) can be expected to occur only about once every 50 years on the average, whereas flood flows of about 47,000 ft^3/s (about 1,320 m^3/s) could be expected at that site about once in 10 years, on the average.

For design of various hydraulic structures, as well as for floodplain zoning, it is common to derive estimates of the height of flood water and extent of flooding that might be expected on the average of once in 100 years (fig. 1D). This is commonly referred to as the "100-year flood". For the streams shown on the map with blue patterns, information on the extent of flooding is available, and is generally based on the occasional or 100-year flood. If this recurrence interval seems too long for a particular planning need, flood flows for a shorter recurrence interval can be estimated also (fig. 2).

The natural flood-flow interpretations must be adjusted for the effects of flood-control facilities or other regulation of high flows, and also for effects of urbanization. Urban development that results in the paving and storm-sewering of a substantial part of a stream's drainage basin can cause a drastic increase in the frequency and intensity of flooding (Leopold, 1968). This effect of urbanization alone can largely offset the benefits derived from expensive flood-control construction.

Of course, the estimated recurrence frequencies for floods are only averages over a long period of time. It is entirely possible for two or more major floods to occur within a period of a few years, or even within the same year. Conversely, a major flood may not occur for several decades--long enough for us to forget that a flood hazard exists.

Coastal Flooding

Shorelines and the lower parts of major stream valleys are subject to flooding caused by natural events that are less predictable than storm runoff but nonetheless are possible occurrences in this region. Such events include high winds, major landslides, and submarine earth movements which could produce unusually high and powerful waves on Puget Sound.

The most common causes of coastal flooding are combinations of high tides and strong onshore winds. Although no estimates of probability of this type of flooding are known to the writers, they possibly could be developed from wind data and tidal predictions.

Even less predictable are the possibilities of flooding that might result from sea waves (tsunamis) generated by submarine landslides or faulting. No information is available on the past occurrence of such events in the Puget Sound region. The irregular shorelines and many twisting channels within the Puget Sound system doubtless would rapidly dampen and dissipate any tsunamis generated in the Pacific Ocean. However, experience from the Alaska earthquake of 1964 indicates that earth faulting and landslides triggered by intense earthquakes can generate violent local waves in such confined waters (Eckel, 1970, p. 16-17, 23-25). Delta deposits at the mouths of streams in Alaska were especially susceptible to rapid sliding that produced the waves. Underwater slides triggered by the earthquake caused violent waves that radiated outward from the delta face and others that swept backward (landward) over the delta.

Most of the damage from coastal flooding in the Puget Sound region will be to areas that are less than 20 feet above the average level of adjacent open-water bodies--Puget Sound and the large lakes such as Lake Washington. Sizeable areas lying generally within that 20-foot-altitude zone are delineated on the map, including stream-mouth areas of the Duwamish River (Seattle) and the Puyallup River (Tacoma) which contain industrial concentrations that could be greatly damaged. Because of the high banks and bluffs at the shoreline, most of the near-shore parts of the map area would receive no direct damage from this type of flooding. However, within the 20-foot zone along these banks there are dozens of miles of streets, highways, and railroads that are susceptible to damage or disruption by coastal flooding and waves.

The extent to which coastal flooding can proceed up the stream valleys depends not only on the height of the coastal flooding but also on its duration, the concurrent height of the stream water, and the presence of flood-control measures such as dikes and levees.

Catastrophic Events in Mountains

The mountainous headwater areas of major streams in the region provide a setting for flooding that could result from catastrophic events such as landslides, dam failures, mudflows, or debris flows that affect major streams, lakes, or reservoirs. Water stored in natural lakes or manmade reservoirs, if released suddenly, would produce floods that far exceed those due to natural storm runoff or snowmelt. Therefore, the sudden failure of a dam impounding a sizable reservoir, or the sudden displacement of water in a lake or reservoir by a landslide or mudflow, could create a flood of disastrous proportions through the stream channel all the way to Puget Sound. Such catastrophic floods could take a heavy toll in lives as well as property because they probably would occur without much warning, and because flood levels resulting from such events likely would be substantially above the normal "design" flood levels. Shown on the map and listed in the "explanation" are dams and reservoirs in this region that conceivably could be impacted by such catastrophic events.

The greatest liklihood of such catastrophic flooding probably exists for the streams that drain glaciers, especially the glaciers on Mount Rainier. The map explanation lists these streams and the glaciers that feed them.

Geologic evidence of the eruptive history of Mount Rainier indicates that this quiescent volcano will likely erupt again within the next few hundred years; however, at present there is no way to predict the time, type, or intensity of the eruption (Crandell and Mullineaux, 1967, p. 21 and 24). For this area, the chief hazards from such future eruptions will be mudflows and floods moving along valley floors. The largest mudflows in the past were formed when huge masses of rock debris and clay were saturated by water (snow and glacial ice melted by volcanic heat) and avalanched from the top and sides of the volcano. These became mudflows tens to hundreds of feet deep and traveled as much as 65 miles downvalley. Other mudflows were not directly related to volcanic activity but were caused by rain and melting snow or by the periodic release of water held in a glacier. At least 55 different mudflows of various sizes have left deposits in the valleys that head on Mount Rainier (Crandell, 1973).

Mudflows can be especially dangerous because of their possible large size, their ability to travel many miles, and the speed with which they can move (some reported at 20-55 miles per hour). Not only do they constitute a special type of flooding, but they can fill reservoirs and severely damage dams, and also can cause tremendous floods farther downstream by displacing reservoir water, causing it to overspill dams (Crandell, 1973).

PLANNING RESPONSE AND ADEQUACY OF DATA

Any effective planning response to flood hazards, whether it is the design of flood-control works or decisions regarding floodplain zoning, requires a realistic evaluation of the hazard, based upon a sound interpretation of the hydrologic and geologic conditions that influence the flooding. The general availability and adequacy of flood-hazard information for land-use planning are outlined below; agencies that can supply additional information are listed in "Sources of Information".

Runoff Flooding

Until recently, state, local, and some federal governmental agencies sponsored and heavily favored flood-control works as a means of reducing life and property losses. There is now widespread agreement, however, that land-use regulation must be applied in conjunction with the traditional flood-control measures.

The available data about flooding from storm and snowmelt runoff are helpful but not fully adequate for guidance of planning for this area, and interpretation of the data by specialists commonly is required. Flood-frequency studies and the mapping of flood-prone areas are continuing by the Geological Survey and other agencies (see "Sources of Information"), and are being refined through the continuing programs of data collection and research. Snow surveys and other periodic inventories of the water content of the mountain snowpack are being expanded and improved, and instruments to monitor and transmit snow-water data from remote sites are being used increasingly. Research is also under way on the possible use of images obtained by high-altitude aircraft or satellites for rapid regional inventory of snowfields and glaciers. Satellite images also are being used for improved forecasting of the arrival, water content, and flood potential of storms.

To be more useful for land-use planning, the data presently available on flood frequencies and inundated areas need to be extended and related more to potential losses. For example, information also is needed about water depths and velocities and probable duration of flooding, as a basis for estimating damage potential to crops, structures, and activities of man. The damage-potential information, in turn, allows a comparison and balance of projected benefits of various land uses against predictable flood losses in different parts of the flood-prone areas.

Probably the least available information on runoff flooding in the Puget Sound lowland is on the degree to which urbanization intensifies the runoff. Although considerable research on this subject has been done in other areas (Leopold, 1968), the precipitation on the Puget Sound lowland is generally less intense and more persistent than in those other areas; consequently the engineering guidelines for urban runoff that were developed elsewhere may not apply to this area (Foxworthy and Richardson, 1973).

Coastal Flooding

Little, if any, published information is available on coastal flooding in the Puget Sound area. The recurrence frequency of combined conditions of high tides and strong winds doubtless can be estimated roughly from data held by agencies of the National Oceanographic and Atmospheric Administration (National Ocean Survey, and National Weather Service). No satisfactory method now exists for evaluating the flood hazard in this area from violent sea waves such as tsunamis, although some areas of substantial hazard doubtless can be delineated (some deltas and the shores opposite them, for example). The Puget Sound lowland is an earthquake-prone area, and this type of flooding is likely to be triggered by or associated with earthquakes. Therefore, better evaluation of this type of flood hazard requires the location of active fault zones where crustal movement might produce strong earthquakes, as well as determination of the frequency of strong earthquakes--studies which are now underway.

Dams and Reservoirs

The degree to which dams and reservoirs might increase the danger of downstream flooding depends on the integrity of the dam, its abutments and foundation rocks, and on the likelihood of an overspill of impounded water as a result of landslides or debris flows. The sites of most, if not all, of the major dams in the area received detailed geologic study before the dams were built. At that time the stability of foundation rocks was evaluated; any problems presumably were met during design and construction of the dam. The rock masses overlooking the reservoir basins, however, were seldom subjected to such careful study, and no evaluation of the stability of these rocks can be made until such study is accomplished. Because earthquakes are a likely trigger for the displacement of any unstable rock masses, studies to delineate fault zones and to determine earthquake hazards will be valuable in such evaluation. Studies and monitoring to improve the prediction of volcanic activity and glacier-outburst floods also can improve the evaluation.

A framework for safety inspections of dams in this region exists in regulations involving the Federal Power Commission (for hydropower dams), U.S. Army Corps of Engineers, and Washington Department of Ecology. However, field inspection activities will need to be substantially intensified before the soundness and safety of the dams and reservoirs shown on the map can be fully evaluated.

Pending a better evaluation of the hazard associated with the sudden release of impounded water, the areas that would be flooded can be determined for various types of reservoir spills, and at various reservoir levels. The areas vulnerable to such flooding can be determined from reservoir-volume information available from the agencies that operate the reservoirs, using flood-routing and other indirect methods of flood analysis. (See "Runoff and Snowmelt", above.) Once these areas are delineated on a map, the information can be incorporated into planning just as with the more normal runoff floods.

Glaciers and Volcanic Activity

Research is underway which should improve capabilities for evaluating flood hazards, including mudflows, associated with glacier outbursts and volcanic activity. This research includes the use of instruments to detect and record earthquakes which might provide warning of an eruption of Mount Rainier, monitoring of the heat patterns of the volcano from an aircraft once or twice a year, and studies of the movement and water content of glaciers in the Cascade Range. Estimates of the frequency of eruptions and other events already are available from detailed studies on Mount Rainier (Crandell and Mullineaux, 1967, tables 1 and 2). Several glacier outburst floods in western Washington, which are not known to be related to volcanic activity, have been described by Richardson (1968). Also, a detailed study by Hodge (1974) shows a relation between the rate of movement of a glacier and outbursts of water from it.

The methods recommended by Crandell (1973) for reducing the risks from mudflows and associated floods originating on Mount Rainier can be applied also to other parts of the area. These include: (1) developing plans for evacuation of valley floors during volcanic eruptions or upon notice of a mudflow, (2) development of a communications system whereby residents can be warned of a mudflow (or other flood) moving toward them, (3) zoning the valley floors against development in high-risk areas, and (4) draining downvalley reservoirs at the first sign of an eruption.

EXPLANATION

Stream Reaches for which Flood-Hazard Data Exist

Data are mainly in the form of maps showing areas where flooding is likely at least once every 100 years, on the average.

Floodplains narrower than about one-fourth of a mile (400 metres) are shown as a band of that width.

Floodplains wider than about one-fourth of a mile (400 metres) are shown in full extent.

Streamgaging station for which flood-frequency data are available.

Lowlying Areas Vulnerable to Coastal Flooding

Sizeable areas that are generally less than 20 feet above average levels of adjacent open-water bodies, where waves or strong onshore winds may cause or contribute to flooding.

Dams and Reservoirs

Impounded water is potential hazard in cases of major landslides, avalanches, mudflows, or outburst floods entering reservoirs. Data from Pacific Northwest River Basins Commission, 1970, except as noted.

A Snohomish County P.U.D. No. 1 dam and 34,500 acre-foot reservoir (Spada Lake) on Sultan River; no flood control, strictly water supply for City of Everett.

B City of Seattle Axis Dam and 58,000 acre-ft reservoir on South Fork Tolt River; no flood control, strictly water supply.

C Masonry Pool (16,000 acre-ft) and Chester Morse Lake (52,000 acre-ft of active storage) on Cedar River; both for power generation, flood control only incidental. A slide and washout at Cedar Reservoir (formerly impounded by a rock-fill, timber-rib dam) Dec. 1918 washed about 1 million cubic yards of sand and gravel downstream (Mackin, 1941, p. 468-469).

D Howard A. Hanson Dam and Reservoir on Green River (105,600 acre-ft maximum capacity), designed to control floods with recurrence interval greater than 100 years. Mainly flood control, but conservation pool is maintained for augmenting low flows.

E Mud Mountain Dam and Reservoir on White River, 106,000 acre-ft maximum storage; strictly flood control.

F La Grande Dam and Reservoir, storage capacity about 2,700 acre-ft; City of Tacoma, strictly hydropower.

G Alder Dam and Lake, Nisqually River, storage capacity 232,000 acre-ft. Mainly City of Tacoma hydropower; no firm flood-control storage, but when a flood is expected and Alder Lake is at maximum stage, the reservoir is drawn down about 4 to 6 ft. providing storage for about 10,000 to 15,000 acre-ft.

Streams that Drain Glaciers

Most likely to be affected by mudflows or glacier-outburst floods.

1 Tributaries of Skykomish River: North Fork Skykomish River fed by Columbia Glacier via Blanca Lake; smaller glacier west of Columbia Glacier feeds Silver Creek. East Fork Foss River fed by Hinman, Lynch, and other glaciers of Mt. Hinman and Mt. Daniel.

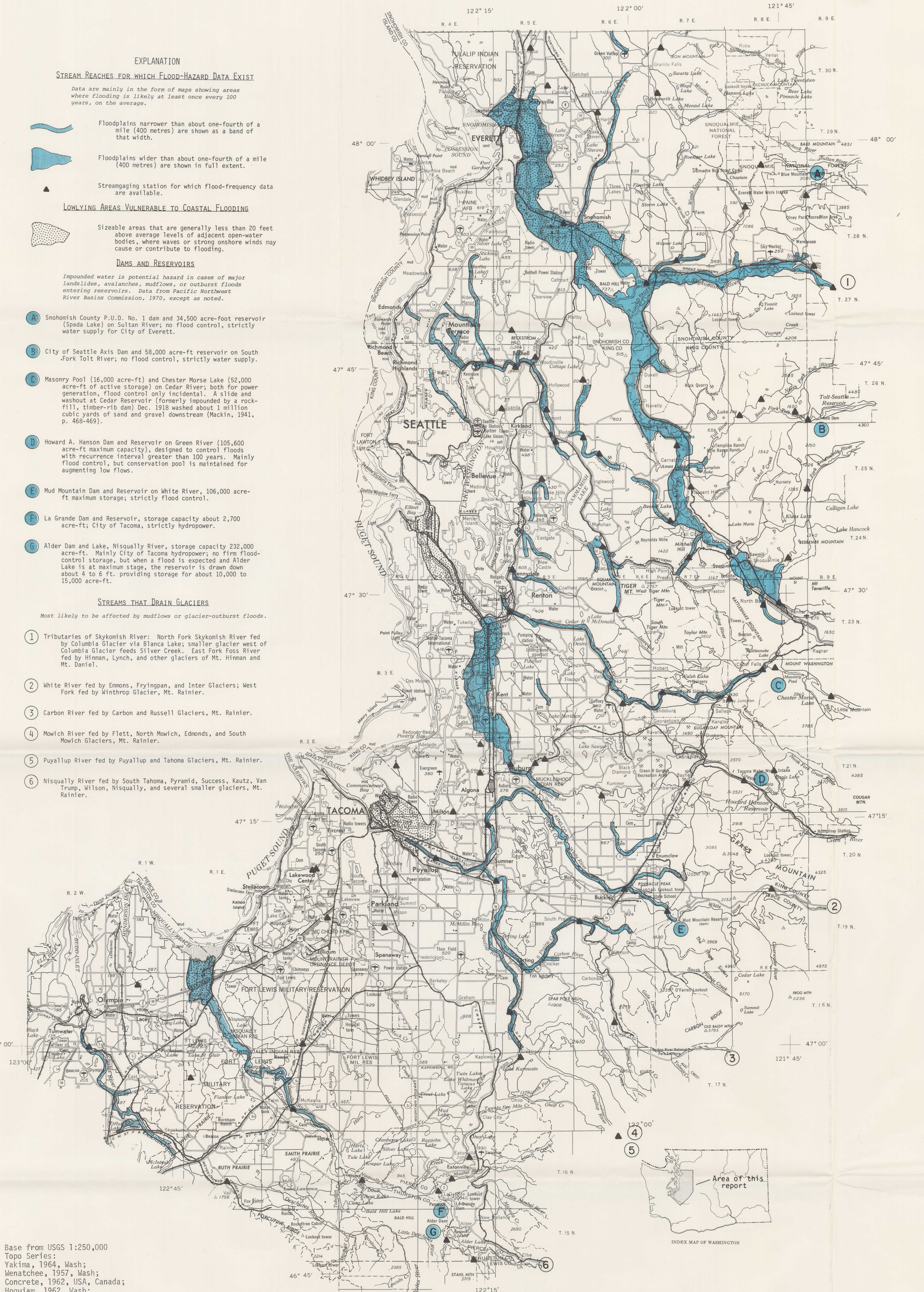
2 White River fed by Emmons, Fryingpan, and Inter Glaciers; West Fork fed by Winthrop Glacier, Mt. Rainier.

3 Carbon River fed by Carbon and Russell Glaciers, Mt. Rainier.

4 Mowich River fed by Flett, North Mowich, Edmonds, and South Mowich Glaciers, Mt. Rainier.

5 Puyallup River fed by Puyallup and Tahoma Glaciers, Mt. Rainier.

6 Nisqually River fed by South Tahoma, Pyramid, Success, Kautz, Van Trump, Wilson, Nisqually, and several smaller glaciers, Mt. Rainier.



Base from USGS 1:250,000
Topo Series:
Yakima, 1964, Wash;
Wenatchee, 1957, Wash;
Concrete, 1962, USA, Canada;
Hoquiam, 1962, Wash;
Seattle, 1961, Wash;
Victoria, 1957, USA & Canada;
Compiled Menlo Park Base Map Section
(6-74)(14-20)
Scale 1:250,000

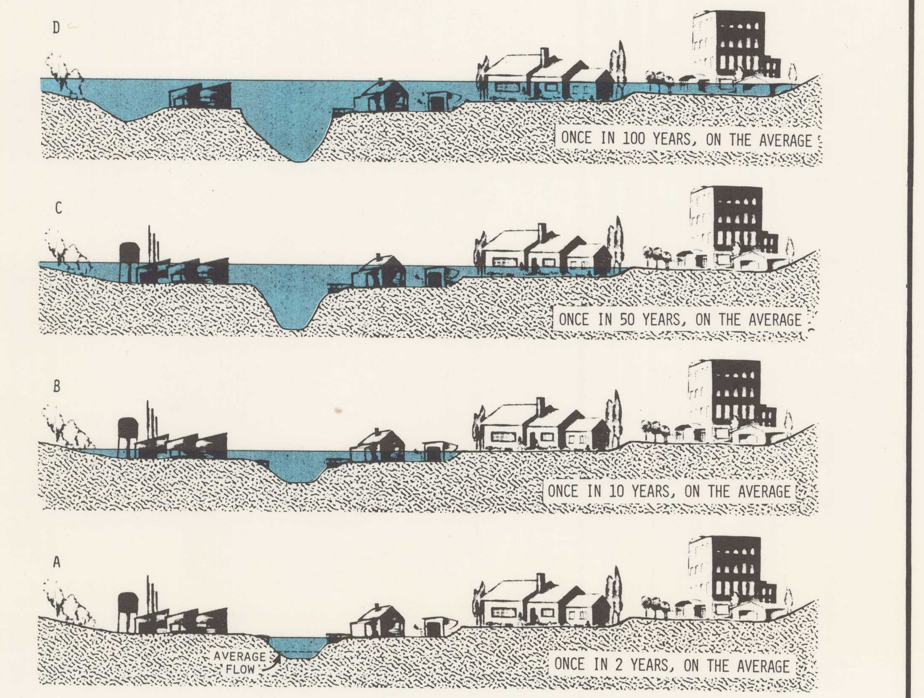


FIGURE 1.--RELATIVE FLOOD LEVELS OF A TYPICAL UNREGULATED STREAM (MODIFIED FROM BUE, 1967). FLOOD LEVELS AND RECURRENCE PERIODS SHOWN HERE REPRESENT LONG-TERM AVERAGES; 2 OR MORE MAJOR FLOODS MIGHT OCCUR DURING SUCCESSIVE YEARS, OR EVEN DURING THE SAME YEAR.

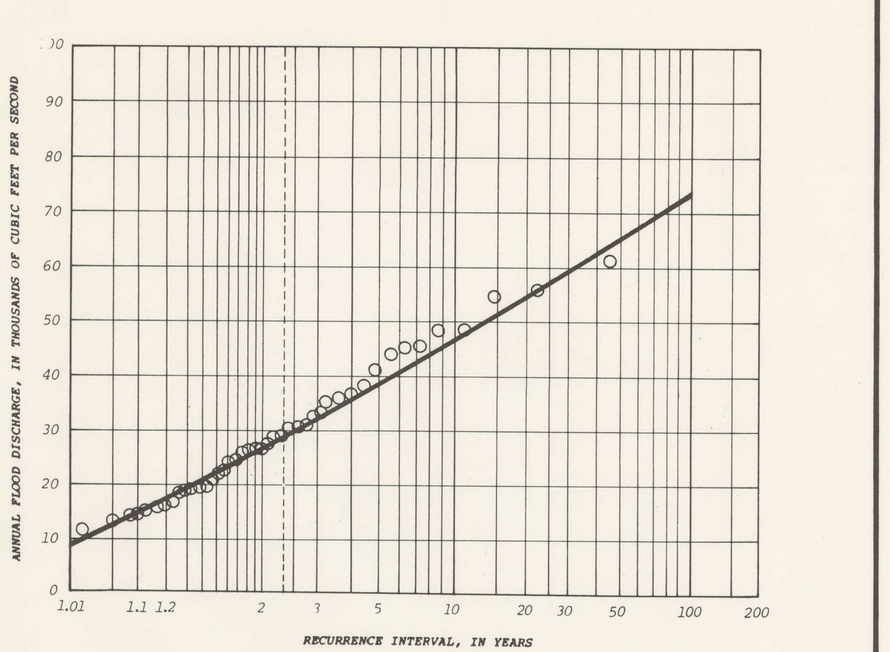


Figure 2.--Graph showing how often, on the average, flood flows of various rates will recur on the Snoqualmie River at a gaging station near Snoqualmie, Wash.

SOURCES OF INFORMATION

Besides the authors of the published references listed below, the following agencies can provide additional flood-hazard information in the categories shown:

Runoff Flooding

U.S. Geological Survey
U.S. Army Corps of Engineers
U.S. Department of Housing and Urban Development
National Weather Service
U.S. Soil Conservation Service
Washington Department of Ecology

Coastal Flooding

U.S. Army Corps of Engineers
U.S. Geological Survey
National Coast Survey
National Weather Service

Dams and Reservoirs

U.S. Army Corps of Engineers
Federal Power Commission
Washington Department of Ecology
Seattle Lighting Department
Seattle Water Department
Snohomish County Public Utility District
Tacoma Public Utilities Department

Glaciers and Volcanic Activity

U.S. Geological Survey
University of Washington, Geophysics Program

REFERENCES

Bue, Conrad D., 1967, Flood information for flood-plain planning: U.S. Geol. Survey Circ. 539, 10 p., 3 figs.

Crandell, Dwight R., 1973, Map showing potential hazards from future eruptions of Mount Rainier, Washington: U.S. Geol. Survey Misc. Geol. Inv. Map I-836 (map with text).

Crandell, D.R., and Mullineaux, D.R., 1967, Volcanic hazards at Mount Rainier, Washington: U.S. Geol. Survey Bull. 1238, 26 p., 5 figs.

Cummans, J.E., Collings, M.R., and Nassar, E.G., 1974, Magnitude and frequency of floods in Washington: U.S. Geol Survey Open-File Rept. 74-336, 46 p., 3 pls.

Eckel, Edwin B., 1970, The Alaska Earthquake, March 27, 1964: lessons and conclusions: U.S. Geol. Survey Prof. Paper 546, 57 p., 2 figs.

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Hodge, Steven M., 1974, Variations in the sliding of a temperate glacier: Jour. Glaciology, v. 13, no. 69, p. 349-369, 15 figs.

Leopold, Luna B., 1968, Hydrology for urban land planning--a guidebook on the hydrologic effects of urban land use: U.S. Geol. Survey Circ. 554, 18 p., 8 figs.

Mackin, J. Hoover, 1941, Glacial geology of the Snoqualmie-Cedar area, Washington: Jour. Geology, v. 49, no. 5, p. 449-481, 12 figs.

Pacific Northwest River Basins Commission, 1970, Flood control, in Comprehensive study of water and related land resources, Puget Sound and adjacent waters, State of Washington: Puget Sound Task Force, app. 12, 252 p., 94 figs.

Richardson, Donald, 1968, Glacial outburst floods in the Pacific Northwest: U.S. Geol. Survey Prof. Paper 600-D, p. D79-D86.

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