UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY ESTIMATE OF POSSIBLE FLOOD ELEVATIONS IN THE COLUMBIA RIVER AT TROJAN NUCLEAR POWER PLANT DUE TO FAILURE OF DEBRIS DAM BLOCKING SPIRIT LAKE, WASHINGTON

By David L. Kresch and Antonius Laenen

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Cover: Photograph of Trojan Nuclear Plant by Jeff Becker
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METRIC CONVERSION FACTORS

Multiply	By	To obtain
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
cubic yards (yd^3)	0.7646	cubic meters (m^3)
acre-feet (acre-ft)	1233.	cubic meters (m^3)
	0.001233	cubic hectometers (hm^3)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
	28.32	liters per second (L/s)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

Failure of the debris dam, blocking the outflow of Spirit Lake near Mount St. Helens, could result in a mudflow down the Toutle and Cowlitz Rivers into the Columbia River. Flood elevations at the Trojan Nuclear Power Plant on the Columbia River, 5 miles upstream from the Cowlitz River, were simulated with a hydraulic routing model. The simulations are made for four Columbia River discharges in each of two scenarios, one in which Columbia River floods coincide with a mudflow and the other in which Columbia River floods follow a mudflow sediment deposit upstream from the Cowlitz River. In the first scenario, Manning's roughness coefficients for clear water and for mudflow in the Columbia River are used; in the second scenario only clear-water coefficients are used.

The grade elevation at the power plant is 45 feet above sea level. The simulated elevations exceed 44 feet if the mudflow coincides with a Columbia River discharge that has a recurrence interval greater than 10 years (610,000 cubic feet per second); the mudflow is assumed to extend downstream from the Cowlitz River to the mouth of the Columbia River, and Manning's roughness coefficients for a mudflow are used. The simulated elevation is 32 feet if the mudflow coincides with a 100-year flood (820,000 cubic feet per second) and clear-water Manning's coefficients are used throughout the entire reach of the Columbia River. The elevations exceed 45 feet if a flow exceeding the 2-year peak discharge in the Columbia River (410,000 cubic feet per second) follows the deposit of 0.5 billion cubic yards of mudflow sediment upstream of the Cowlitz River before there has been any appreciable scour or dredging of the deposit. In this simulation it is assumed that (1) the top of the sediment deposited in the Columbia River is at an elevation of 30 feet at the mouth of the Cowlitz River, (2) the surface elevation of the sediment deposit decreases in an upstream direction at a rate of 2.5 feet per mile, and (3) clear-water Manning's coefficients apply to the entire modeled reach of the Columbia River.

INTRODUCTION

The explosive May 18, 1980, eruption of Mount St. Helens, in southwestern Washington, deposited nearly 4 billion cubic yards of debris in the upstream 18 miles of the North Fork Toutle River valley (R. J. Janda, U.S. Geological Survey, oral commun., 1983). The former outlet of Spirit Lake was blocked by debris ranging in depth to 500 feet. The contents of Spirit Lake increased from 123,000 acre-feet in the summer of 1980 to 275,000 acre-feet in December 1982. If the lake were to fill to the existing top of the debris dam, its contents would be 500,000 acre-feet.

Swift and Kresch (1983) identified mudflow flood hazards along the Toutle and Cowlitz Rivers associated with a hypothetical breach of the Spirit Lake debris blockage. The outbreak flood was assumed to entrain 2.4 billion cubic yards of sediment in a mudflow that had a sediment concentration of 65 percent by volume. The mudflow was hydraulically routed through the Toutle and Cowlitz Rivers (see fig. 1). A mudflow is a flowing water-sediment mixture in which the sediment volume accounts for between 40 and 80 percent of the total volume of the mixture. The discharge of the synthesized mudflow at the mouth of the Cowlitz River rose rapidly to a peak of 1.1 million ft^3/s and then receded over a period of more than 2 days. No attempt was made to account for the probable deposit of sediment along flood plains or within other overflow areas.

The current study of the Columbia River was made in cooperation with the U.S. Nuclear Regulatory Commission (NRC) to estimate the flood levels at the Trojan Nuclear Power Plant, located 5 miles upstream of the Cowlitz River, that could result from the mudflow described by Swift and Kresch (1983). Specifically, NRC asked if flood levels due to such a mudflow might be expected to reach or exceed an elevation of 45 feet, the plant grade elevation. All elevations in this report are above National Geodetic Vertical Datum of 1929.

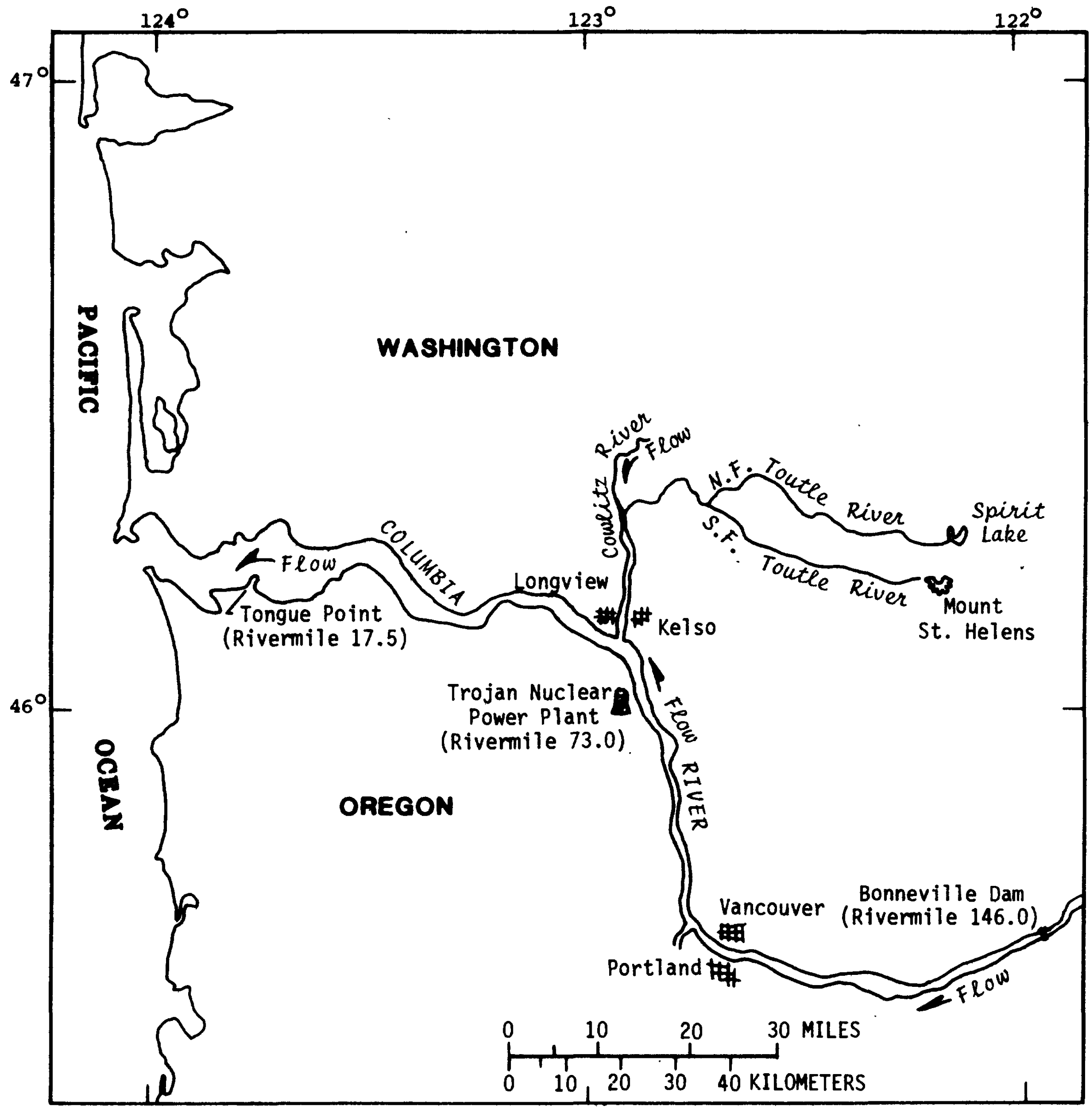

FIGURE 1.--Location of study area and the Trojan Nuclear Power Plant.

APPROACH, ASSUMPTIONS, AND RESULTS

The rapid rate at which the discharge of the mudflow increased dictated that an unsteady-flow computer model be used to analyze the mudflow in the Columbia River. A dam-break flood simulation model (L. F. Land, 1981) was selected. Although the primary purpose of that model is to simulate and hydraulically route dam-break floods, only the routing portion of the model was used. Hydraulic routing in the model is accomplished numerically with the Saint Venant flow equations and a nonlinear implicit finite-difference algorithm.

The model was used to simulate water-surface elevations throughout a 128-mile-long reach of the Columbia River from rivermile 145.5, 1/2 mile downstream of Bonneville Dam, to Tongue Point at rivermile 17.5. The Cowlitz River mudflow was treated as a point source of tributary inflow in the model. Primary inputs to the model were (1) Columbia River cross sections, (2) the discharge hydrograph of the mudflow, (3) Columbia River discharges, (4) Manning's roughness coefficients for the Columbia River, and (5) the initial water-surface elevation at Tongue Point. Discharges for various recurrence intervals were furnished by William Akre (U.S. Corps of Engineers, Portland, Oreg., written commun., 1983).

Twenty-one cross sections were used to define the Columbia River channel geometry. Twenty of these cross sections were obtained from the U.S. Army Corps of Engineers (COE), Portland, Oreg. The underwater segments of some of these cross sections were revised on the basis of more recent data (COE, 1982). One additional cross section, located at rivermile 73.0 at Trojan Nuclear Power Plant, was estimated using USGS 7.5- and 15-minute topographic maps and the 1982 COE report.

Peak stages in the Columbia River estuary at Tongue Point result predominantly from high tides rather than from high river discharges. High tides produce peak elevations of 6 to 9 feet above sea level at Tongue Point; 9 feet was used as the initial elevation at Tongue Point for all simulations.

When the impact of a mudflow is included in a simulation, flood elevations at the Trojan Nuclear Power Plant depend on the shape, duration, and peak discharge of the mudflow hydrograph at the mouth of the Cowlitz River, the discharge in the Columbia River during and subsequent to the mudflow, and the type of flow—clear water or mudflow—that occurs in the Columbia River. It was hypothesized that maximum flood elevations at Trojan would result if (1) the mudflow coincided with a Columbia River flood or (2) the mudflow coincided with high tide during low flow in the Columbia River and was followed by a Columbia River flood before the deposit was scoured or dredged. Therefore, flood elevations at Trojan were simulated for these two scenarios.

Past streamflow records for the Columbia River show that both scenarios are possible. Long periods of high flow result from snowmelt in the upper parts of the Columbia River basin. These high flows pass through many reservoirs. Except during extreme floods, the discharge and duration of flow are largely the result of reservoir operation patterns. Scenario 1 could occur during one of these periods.

The river can also rise from low flow to flood stage in a few days as a result of rain in basins that are tributary to the Columbia River downstream from the most downstream reservoir. In December 1964, a peak flood discharge in excess of the 100-year discharge occurred about 5 days after the start of the rise. Such a flood soon after the mudflow could produce scenario 2.

Scenario 1 - Mudflow Coincides with a Columbia River Flood

If the mudflow coincides with a flood on the Columbia River, the hydraulic properties in the Columbia River could be those of either clear water or a mudflow, depending on how much mixing of the two flows occurs. The Manning's roughness coefficients for the two types of flow differ greatly. Coefficients used for clear water in this study are a function of discharge and ranged from 0.030 for a discharge of 410,000 ft^3/s to 0.027 for a discharge of 820,000 ft^3/s; coefficients for mudflows are a function of flow depth and ranged from 0.180 for shallow flow to 0.060 for deep flow. Mudflow coefficients were computed from the uniform mudflow equation (C. L. Chen, U.S. Geological Survey, oral commun., 1982) that was used by Swift and Kresch (1983). The uniform mudflow equation, which was derived on the basis of the rheological properties of mudflows, is analogous to the uniform flow equation for clear water. Peak flood elevations at the Trojan plant if the mudflow coincides with Columbia River floods were computed with coefficients for both clear water and mudflows. Elevations for four discharges in the Columbia River are presented in table 1.

The computations made with the model showed that if the mudflow entered the Columbia River when the discharge of the Columbia was 410,000 ft^3/s, 5 percent of the mudflow would move up the Columbia River. Upstream flow decreased to zero if the discharge of the Columbia River was 750,000 ft^3/s. Therefore, it was assumed that no sediment was deposited upstream from the Cowlitz River if the mudflow coincided with a flood in the Columbia River. It was further assumed that the sediment would be transported downstream in the Columbia River and that Manning's roughness coefficients for mudflows would apply downstream of the Cowlitz River only if sediment concentrations in the Columbia River exceeded 40 percent by volume.

TABLE 1.--Simulated water-surface elevations in the Columbia River at Trojan Nuclear Power Plant for the coincidence of high tide, a hypothetical mudflow with a peak discharge of 1.1 million ft^3/s in the Cowlitz River, and selected Columbia River discharges

Columbia River flow condition	Columbia River discharge upstream of Cowlitz River (ft^3/s)	Water-surface elevation (feet)	
		a/	b/
2-year peak	410,000	25	38
10-year peak	610,000	28	44
50-year peak	750,000	30	47
100-year peak	820,000	32	48

a/ Computed with Manning's coefficients for clear water.

b/ Computed with Manning's coefficients for a mudflow downstream of the Cowlitz River and clear water upstream of the Cowlitz River.

Scenario 2—Mudflow is followed by a Columbia River Flood

Flood elevations at Trojan produced by a Columbia River flood subsequent to the mudflow depend largely on the height of sediment deposited at and upstream from the Cowlitz River. Maximum upstream flow and sediment deposition from the mudflow would be expected to occur when the Columbia River flow is low. Simulation of the mudflow during a discharge of 10,000 ft^3/s, which is an assumed minimum flow induced by backwater at high tide during low flow in the Columbia River, indicated that 30 percent of the mudflow would travel in an upstream direction. R. L. Dinehart (U.S. Geological Survey, oral commun., 1983) estimated that approximately 30 percent of the mudflow material could be finer than sand size (< 0.062 millimeters) and that this fine material would likely remain in suspension and be transported downstream. His estimate is based on sediment data for the Toutle and Cowlitz Rivers during the mudflows of May 18-19, 1980, and March 19-20, 1982. If the entire 2.4 billion cubic yards of sediment entrained in the mudflow were to reach the Columbia River during low flow and high tide, the volume of solids that would flow up the Columbia River would be 0.72 billion cubic yards. If 30 percent of these solids are fine materials that remain in suspension, 0.5 billion cubic yards of material could be deposited in the Columbia River upstream from the Cowlitz River.

Sediment deposited in the Columbia River during the mudflow of May 1980, described by Haeni (1983), was highest in elevation (about -20 ft) at the mouth of the Cowlitz River, and the elevation of the deposit surface decreased in an upstream direction at a rate of 2.5 feet/mile. If 0.5 billion cubic yards were deposited at the same slope, the deposit in the Columbia River at the Cowlitz River would reach an elevation of about 30 feet.

When the model was used to route Columbia River discharges over the deposit, cross sections upstream from the Cowlitz River were altered in the model to account for deposition. Sections downstream from the Cowlitz River were not altered because little sediment was deposited there during the 1980 mudflow. It was assumed that the deposit was not scoured or dredged prior to, or during the occurrence of the Columbia River discharges. Discharges of the Columbia River were assumed to remain constant for the simulations. Simulated water-surface elevations at Trojan are shown in table 2.

TABLE 2.--Simulated water-surface elevations in the Columbia River at Trojan Nuclear Power Plant for selected Columbia River discharges that follow a mudflow that is assumed to have deposited 0.5 billion cubic yards of sediment in the Columbia River channel upstream from the Cowlitz River. The deposit is assumed to have a maximum surface elevation of 30 feet at the Cowlitz River. The surface elevation decreases in the upstream direction at 2.5 feet per mile

Columbia River flow condition	Columbia River discharge upstream of Cowlitz River (ft^3/s)	Water-surface elevation (ft^3/s)
Low flow	250,000	39
2-year peak	410,000	45
10-year peak	610,000	49
50-year peak	750,000	52

MODEL CONSISTENCY AND SENSITIVITY

The scope of this study was limited by the completion date in the cooperative agreement, and within the time frame available it was possible to make only a few comparisons to examine the consistency and sensitivity of the Dam-Break Flood Simulation Model.

Before the model was used to simulate flood elevations at the Trojan Nuclear Power Plant caused by a Cowlitz River mudflow, results from it for a clear-water Columbia River flood were compared for consistency with those from a Corps of Engineers model. For a Corps of Engineers Standard Project Flood of 850,000 ft^3/s the dam-break model simulated an elevation of 22 feet at the Trojan plant as compared to 21 feet by the Corps of Engineers model (1971).

Also, before the dam-break model was used to simulate the impact of a mudflow, its sensitivity to the initial elevation at Tongue Point was tested. For a constant flood discharge of 740,000 ft^3/s in the Columbia River upstream of the Cowlitz River and a constant flow of 50,000 ft^3/s entering from the Cowlitz, reducing the initial elevation at Tongue Point from 9.0 feet to 0.0 feet lowered the simulated elevation at the Trojan plant by 3 feet. For a constant low flow of 230,000 ft^3/s in the Columbia River adding to a constant flow of 20,000 ft^3/s from the Cowlitz River, the same reduction in the initial elevation lowered the simulated elevation by 7 feet at the Trojan plant.

After the dam-break model was used to simulate the impact of a mudflow, its sensitivity to increasing the Manning's roughness coefficients for clear water from 0.030 to 0.035 at every cross section was tested for two cases. For a case similar to those in scenario 1, except that the discharge of the Columbia River upstream of the Cowlitz River was assumed to be 690,000 ft^3/s, increasing the roughness coefficient raised the simulated elevation at the Trojan plant by 4 feet. For the case in scenario 2 in which the Columbia River discharge was 410,000 ft^3/s, increasing the Manning's coefficient raised the simulated elevation by 2 feet at the Trojan plant.

CONCLUSIONS

Estimates of possible flood elevations in the Columbia River at the Trojan Nuclear Power Plant due to the occurrence of the hypothetical mudflow described by Swift and Kresch (1983) were made with a hydraulic routing model for two scenarios. Simulated flood elevations exceed 44 feet above sea level if the mudflow coincides with a Columbia River discharge that has a recurrence interval greater than 10 years (610,000 ft^3/s) and if Manning's roughness coefficients for a mudflow are used for the Columbia River downstream of the Cowlitz River. Simulated elevations exceed 45 feet if (1) the mudflow deposits 0.5 billion cubic yards of sediment in the Columbia River upstream from the Cowlitz River, (2) the surface elevation of the deposit is 30 feet at the Cowlitz River and decreases in an upstream direction at a rate of 2.5 feet per mile, and (3) prior to any appreciable scour or dredging of the deposit, the Columbia River flow exceeds the 2-year peak dischage (410,000 ft^3/s).

The reliability of the simulated elevations depends primarily on the following assumptions: (1) the magnitude of the mudflow entering the Columbia River, (2) Manning's roughness coefficients for the Columbia River, (3) the initial elevation at Tongue Point on the Columbia River, and (4) the volume and distribution of sediment deposited in the Columbia River upstream from the Cowlitz River. The use of the hypothetical mudflow hydrograph described by Swift and Kresch (1983) as the inflow to the Columbia River is particularly debatable because no allowance was made in that study for sediment to be deposited along the Toutle and Cowlitz Rivers. If sediment were deposited along those rivers, less would reach the Columbia River and less would be deposited in the Columbia.

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