June 1983

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 A LARGE MUDFLOW IN THE COWLITZ RIVER

By David L. Kresch and Antonius Laenen

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report

Prepared in cooperation with the
U.S. NUCLEAR REGULATORY COMMISSION

Tacoma, Washington
1983

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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.

PRELIMINARY ESTIMATE OF POSSIBLE FLOOD ELEVATIONS IN THE COLUMBIA RIVER AT TROJAN NUCLEAR POWER PLANT DUE TO A LARGE MUDFLOW IN THE COWLITZ RIVER

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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, Cowlitz, and Columbia Rivers. The U.S. Nuclear Regulatory Commission (NRC) asked the U.S. Geological Survey (USGS) to determine whether the water-surface elevation in the Columbia River at the Trojan nuclear power plant, located 5 miles upstream of the Cowlitz River, could exceed 45 feet above sea level if a hypothetical mudflow of the proportions (peak discharge 1.1 million cubic feet per second at the mouth of the Cowlitz River) described in the U. S. Geological Survey's Water Resources Investigations Report 82-4125 ("Mudflow Hazards Along the Toutle and Cowlitz Rivers from a Hypothetical Failure of Spirit Lake Blockage," by C. H. Swift and D. L. Kresch, 1983) were to enter the Columbia River. A numerical flood-routing model of the Columbia River indicates that the water-surface elevation at the plant could exceed 45 feet under certain

conditions.

Flood elevations simulated by the model exceed 44 feet for the coincident occurrence of the mudflow and Columbia River flood flows with recurrence intervals greater than 10 years (640,000 cubic feet per second) if Manning's roughness coefficients that simulate the hydraulic properties of mudflows are used for the Columbia River downstream of the Cowlitz River. Simulated flood elevations exceed 45 feet if the mudflow deposits 0.50 billion cubic yards of sediment in the Columbia River upstream of the Cowlitz River at a bedslope of -2.5 feet per mile in the upstream direction and, prior to any appreciable scour or dredging of the deposit, the Columbia River flow exceeds the 2-year peak discharge (430,000 cubic feet per second).

Simulated flood elevations at Trojan do not exceed 32 feet if Columbia River flood flows of 100-year recurrence interval (850,000 cubic feet per second) or less are coincident with the mudflow and Manning's roughness coefficients that simulate the hydraulic properties of clear-water flows are used for the Columbia River.

The reliability of the simulated flood elevations is indeterminate because of uncertainties about the reasonableness of many of the assumptions made for this study. The results presented herein were obtained in accordance with NRC guidelines to determine flood elevations using "conservative" (likely to produce the highest possible flood elevations) "hydrologic modeling techniques and assumptions." A directive from NRC that the mudflow hydrograph generated in WRI Report 82-4125 (Swift and Kresch, 1983) be used as the inflow to the Columbia River is of particular concern because in that report no attempt was made to account for the probable deposit of sediment within overflow areas and along the Toutle and Cowlitz River floodplains. Simulated flood elevations would have been lower if the volume of the mudflow at the mouth of the Cowlitz River had been reduced by the volume of estimated upstream deposits.

INTRODUCTION

The explosive May 18, 1980, eruption of Mount St. Helens, in southwestern Washington, deposited a bulk volume of 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 channel 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.

A previous U.S. Geological Survey (USGS) report (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 with the lake surface elevation assumed to be 3,475 feet above sea level and the lake contents to be 314,000 acre-feet. The resulting clear-water outbreak flood was assumed to entrain 2.4 billion cubic yards of blockage material and produce a mudflow with a sediment concentration of 65 percent by volume that was hydraulically routed through the Toutle and Cowlitz Rivers to the mouth of the Cowlitz River (see figure 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. When sediment volume is less than 40 percent, the water-sediment mixture has the hydraulic properties of a clear-water flow. The peak discharge of the mudflow in the Cowlitz River near its

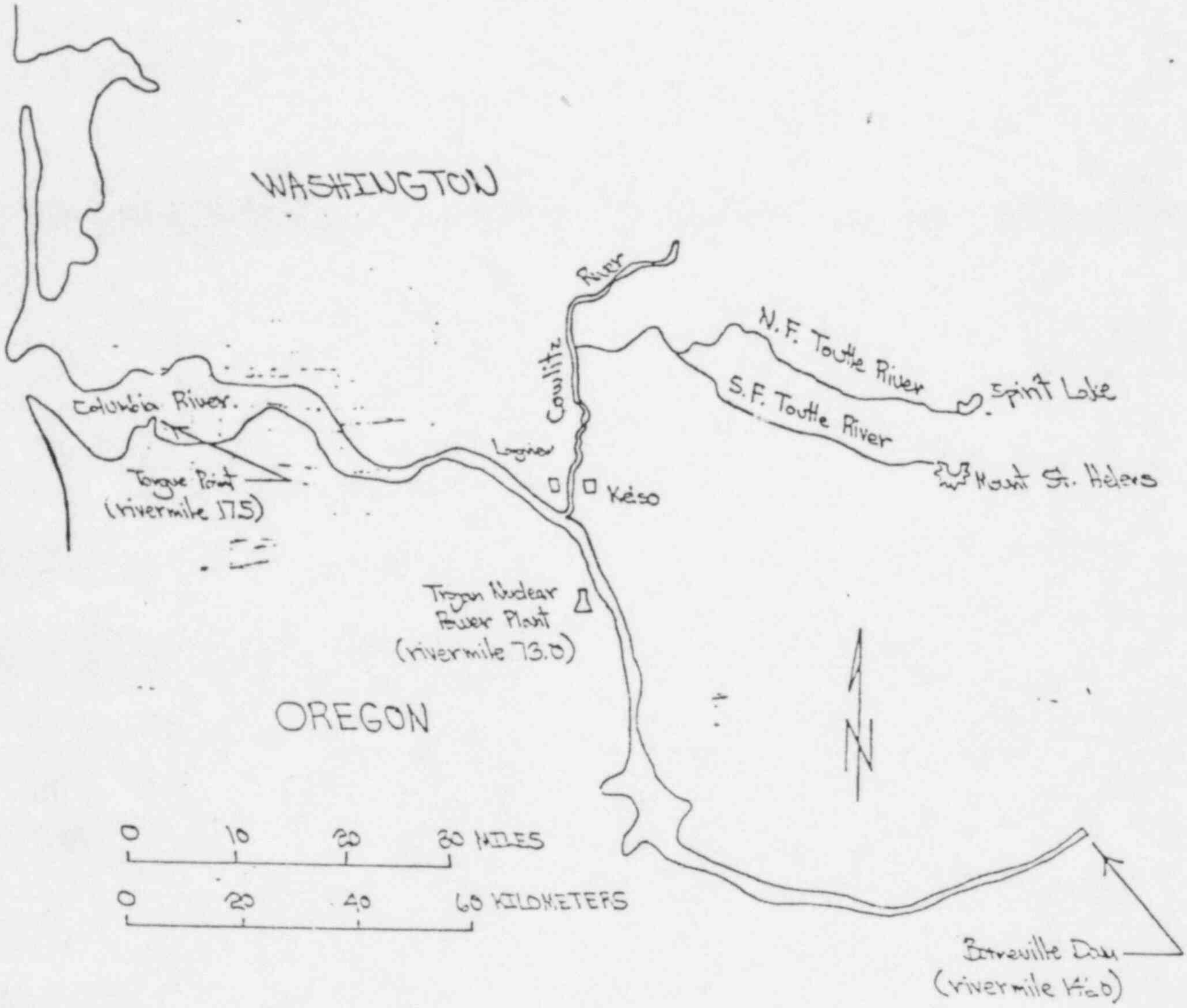

Figure 1.— Map of study area

mouth was 1.1 million ft^3/s, and the duration of mudflow exceeded 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 possibly result from the occurrence of the mudflow described in the previous USGS report. Specifically, NRC wanted to know if flood levels due to the mudflow described in that report might be expected to reach or exceed an elevation of 45 feet above sea level at the plant.

A more extensive USGS analyses of the impact of a mudflow on the Columbia River is currently in progress. Columbia River flood elevations will be simulated in that study using a sediment transport routing model. That study probably will not be completed for at least a year because of major model revisions that are necessary.

APPROACH, ASSUMPTIONS, AND RESULTS

Analysis of the hydraulic characteristics of the confluence of the hypothetical mudflow at the mouth of the Cowlitz River and Columbia River flows required the use of an unsteady flow computer model. USGS model K-634 (L. F. Land, 1981) was selected for use in this study. Although the primary purpose of that model is to simulate and hydraulically route dam-break floods, only the routing portion of the model was utilized in this application. Hydraulic routing in the model is accomplished numerically with the Saint Venant flow equations and a nonlinear implicit finite-difference algorithm.

Model K-634 was used in this study to simulate water-surface elevations throughout a 128-mile-long reach of the Columbia River. The Cowlitz River mudflow was treated as a point source tributary inflow in the model. Primary input data requirements for this application of the model were Columbia River cross sections, the discharge hydrograph of the mudflow at the mouth of the Cowlitz River, Columbia River flood-frequency discharges, Manning's roughness coefficients for the Columbia River, and the initial water-surface elevation at the downstream boundary of the study reach.

Twenty-one cross sections were used to define the Columbia River channel geometry for the 128-mile-long study reach extending from rivermile 145.5, 1/2 mile downstream of Bonneville Dam, to Tongue Point at rivermile 17.5. Twenty of these cross-sections were obtained from

Randy Wortman of the U.S. Army Corps of Engineers (COE), Portland, Oregon. These cross sections have been used by COE in the Columbia River Dynamic Wave Operational (DWOPER) model. 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 generated using USGS 7.5- and 15-minute topographic maps and the 1982 COE report.

The discharge hydrograph for the mudflow at the mouth of the Cowlitz River was obtained from hydraulic simulation computer printouts used in the preparation of WRI Report 82-4125 (Swift and Kresch, 1983). Flood-discharge-frequency information for the Columbia River was obtained from Bruce Duffy (U.S. Corps of Engineers, Portland, Oregon, oral commun., 1983).

Peak stages in the Columbia River estuary at Tongue Point result predominantly from high tides rather than from high river discharges. Extreme high tides produce peak elevations of 6 to 9 feet above sea level at Tongue Point. As a conservative approach, an elevation of 9.0 feet was used as the initial downstream boundary condition at Tongue Point for all simulations.

The model was first checked for reliability before using it to analyze the impact of the mudflow on Columbia River flood elevations. A Columbia River 100-year flood (850,000 ft^3/s) was simulated and the computed water-surface elevation at the Trojan nuclear power plant, 22 feet above sea level, was 1 foot higher than the elevation shown on a COE flood profile (COE, 1971) for the same flood.

The magnitude of Columbia River flood elevations at the Trojan nuclear power plant are dependent not only on the shape, duration, and peak discharge of the mudflow hydrograph at the mouth of the Cowlitz River, but also to a large degree on the Columbia River discharge during and subsequent to the occurrence of the mudflow and the hydraulic characteristics of the mudflow material. Maximum flood elevations at Trojan, it was hypothesized, would most likely result from either (1) the coincident occurrence of the mudflow and a Columbia River flood discharge or (2) the occurrence of Columbia River flood flows subsequent to the mudflow entering and depositing sediment in the Columbia River during low flow. Therefore, flood elevations at Trojan were simulated for both of these scenarios.

Scenario 1--Coincident Occurrence of Mudflow and Columbia River Floods

The hydraulic properties of the mudflow, combined with Columbia River flood flows, could be those for either a clear-water flow or a mudflow depending on how much mixing of the two flows occurs. The Manning's roughness coefficients used for clear-water flows in this study are a function of discharge and ranged from 0.030 for a discharge of 430,000 ft^3/s to 0.027 for a discharge of 850,000 ft^3/s. These roughness coefficients correspond closely with those used by the COE in the DWOPER model. Manning's roughness coefficients used to simulate mudflows are a function of flow depth and ranged from 0.180 for shallow flow to 0.060 for deep flow. These mudflow roughness coefficients were computed from a uniform mudflow equation (C. L. Chen, U.S. Geological Survey, oral commun., 1982) and are similar to those used for the mudflow in Water Resources Investigations Report 82-4125 (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 were computed for clear water and mudflow conditions for the coincident occurrence of the mudflow and several peak flood discharges in the Columbia River and are presented in table 1.

TABLE 1.--Simulated water-surface elevations in the Columbia River at Trojan nuclear power plant for the coincident occurrence of a hypothetical mudflow with a peak discharge of 1.1 million ft^3/s near the mouth of the Cowlitz River and selected Columbia River peak discharges

Columbia River flow condition	Columbia River peak discharge (ft^3/s)	Water-surface elevation (feet above sea level) a/	b/
2-year peak	430,000	25	38
10-year peak	640,000	28	44
16-year peak	685,000	29	45
50-year peak	790,000	30	47
100-year peak	850,000	32	48

a/ Hydraulic properties assumed to be those of a clear-water flow.

b/ Hydraulic properties assumed to be those of a mudflow downstream of the Cowlitz River and of a clear-water flow upstream of the Cowlitz River.

An initial assumption that very little, if any, sediment would be deposited in the Columbia River upstream of the Cowlitz River for the coincident occurrence of the mudflow and Columbia River floods was checked for reliability by analyzing computer output from the model. Comparison of Columbia River discharge hydrographs generated by the model for two cross sections, one located 1 mile upstream and the other 2 miles downstream of the Cowlitz River, indicates that for a Columbia River discharge of 430,000 ft^3/s approximately 5 percent of the incoming mudflow would travel upstream and that there would be no upstream flow for a Columbia River discharge of 790,000 ft^3/s. Considering these comparisons to at least relatively confirm the validity of the initial assumption, no channel adjustments were made to account for potential sediment deposition in the Columbia River upstream of the Cowlitz River.

Scenario 2--Columbia River Floods Subsequent to Mudflow Sediment Deposit

The magnitude of flood elevations at Trojan produced by Columbia River flood flows subsequent to mudflow sediment deposition in the Columbia River depends to a large degree on the elevation of the top of the deposit upstream of the Cowlitz River. An estimate of the maximum deposit elevation upstream of the Cowlitz River was made by assessing (1) the amount of sediment deposited, and (2) the slope and areal distribution of the deposit. The reasonableness of these deposit characteristics is of critical importance to the accurate simulation of Columbia River flood elevations at Trojan.

Maximum upstream flow and sediment deposition of the mudflow would be expected to occur during a Columbia River low flow. Simulation of the Columbia River at low flow indicated that 30 percent of the mudflow would travel in an upstream direction. R. L. Dinehart (U.S. Geological Survey, oral commun., 1983) suggested, on the basis of analysis of sediment data collected for the Toutle and Cowlitz Rivers during the May 18-19, 1980, and March 19-20, 1982, mudflows, that approximately 30 percent of the mudflow material may be finer than sand size (< 0 .062 millimeters) and that this fine material will likely remain in suspension and be transported downstream. If the entire 2.4 billion cubic yards of the Spirit Lake blockage contained in the mudflow is assumed to be transported to the mouth of the Cowlitz River, the bulk volume of solids in the 30 percent assumed to flow upstream in the Columbia River is 0.72

billion cubic yards. Assuming 30 percent of these solids are fine materials that remain in suspension, leaves 0.50 billion cubic yards of material to be deposited upstream in the Columbia River.

The slope and areal distribution of the mudflow deposit was estimated on the basis of the sediment deposited during the May 18-19, 1980, mudflow. That deposit, which is described in a report by Haeni (1983), was greatest in thickness at the mouth of the Cowlitz River and had a surface sloping upstream at an average rate of -2.5 feet per mile. Using that same slope to deposit the 0.50 billion cubic yards of material upstream, the deposit in the Columbia River would reach an elevation of approximately 30 feet above sea level upstream of the Cowlitz River.

The cross sections in the hydraulic-routing model were altered to account for anticipated sediment deposition by increasing bed elevations as necessary. Selected Columbia River flood flows were then routed through the altered channel to determine corresponding flood elevations at the Trojan nuclear power plant. For the purpose of these computations, it was assumed that the deposit was not scoured prior to or during the flood flows. The simulated water-surface elevations are shown in table 2.

TABLE 2.--Simulated water-surface elevations in the Columbia River at Trojan nuclear power plant for selected Columbia River peak discharges subsequent to a deposit of mudflow sediment in the Columbia River channel. The deposit is assumed to have a volume of 0.50 billion cubic yards upstream from the Cowlitz River with a surface slope of -2.5 feet per mile in the upstream direction.

Columbia River flow condition	Columbia River peak discharge (ft^3/s)	Water-surface elevation (feet above sea level)
Low flow	250,000	39
2-yr peak	430,000	45
10-yr peak	640,000	49
50-yr peak	790,000	52

MODEL SENSITIVITY TESTS

Sensitivity of the water-surface elevations simulated by the model to (1) the initial tide elevation at Tongue Point and (2) the Manning's roughness coefficient for clear-water flows was evaluated.

For an initial tide elevation of 0.0 feet above sea level rather than 9 feet, the simulated elevation at the Trojan plant decreased 3 feet for a mudflow coincident with a Columbia River flood flow of 790,000 ft^3/s, and 7 feet when coincident with a flood flow of 250,000 ft^3/s, using Manning's roughness coefficients for clear-water flow in the Columbia River.

Model sensitivity to Manning's roughness coefficient for clear water was investigated for two cases using coefficients 0.005 greater than those used in this analysis. The simulated water-surface elevation at Trojan increased 4 feet for the coincident occurrence of the mudflow and a Columbia River flood discharge of 640,000 ft^3/s. For a Columbia River flood discharge of 430,000 ft^3/s, subsequent to deposit of mudflow sediment in the channel, the water-surface elevation increased by 2 feet.

CONCLUSIONS

Preliminary estimates of possible flood elevations in the Columbia River at Trojan nuclear power plant due to the occurrence of the hypothetical mudflow described by Swift and Kresch (1983) were made for two scenarios with a hydraulic routing model. Simulated flood elevations exceed 44 feet above sea level for the coincident occurrence of the mudflow and Columbia River flood flows with recurrence intervals greater than 10 years (640,000 ft^3/s) if Manning's roughness coefficients that simulate the hydraulic properties of mudflows are used for the Columbia River downstream of the Cowlitz River. Simulated elevations exceed 45 feet if the mudflow deposits 0.50 billion cubic yards of sediment in the Columbia River upstream of the Cowlitz River at a bedslope of -2.5 feet per mile in the upstream direction and prior to any appreciable scour or dredging of the deposit, the Columbia River flow exceeds the 2-year peak discharge (430,000 ft^3/s).

The reliability of the simulated elevations depends primarily on the reasonableness of the assumed value of (1) the magnitude of the mudflow entering the Columbia River, (2) the Columbia River Manning's roughness coefficients, (3) the tide level at Tongue Point on the Columbia River, and (4) the volume and distribution of sediment deposited upstream in the Columbia River by the mudflow. The use of the hypothetical mudflow hydrograph described in the 1983 report as the inflow to the Columbia River, which was a study directive from NRC, is particularly questionable because that report did not include an analyses of the amount of sediment that might be deposited prior to the arrival of the mudflow at the mouth of the Cowlitz River.

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