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SPIRIT LAKE DAM-FAILURE FLOOD ROUTING ASSESSMENT

By David L. Kresch

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ABSTRACT

Potential clear-water floodflows resulting from uncontrolled breaching by Spirit Lake of a debris dam deposited by the May 18, 1980, eruption of Mount St. Helens, Washington, were evaluated. U.S. Geological Survey dam-break model K-634 was utilized, first to compute clear-water flood hydrographs for various hypothetical breach scenarios, and then to hydraulically route them downstream to the mouth of the Toutle River.

INTRODUCTION

The May 18, 1980, eruption of Mount St. Helens in southwestern Washington deposited rock, ice, vegetation, ash, and mud in the upper North Fork Toutle River valley to a depth of 500 feet in the vicinity of Spirit Lake, thus blocking the outlet of the lake. Field observations of this debris dam blockage indicate that in the vicinity of Spirit Lake it is mantled, to depths of tens of feet, by extremely fine-grained and erodible blast and ash-cloud deposits; consequently, overtopping of its crest by Spirit Lake could result in rapid downcutting or breaching into the dam, thereby discharging tens of thousands of acre-feet of water into the North Fork Toutle River within a short time. Although overtopping of the debris dam is not the only mechanism by which a dam breach could occur, that is the only mechanism considered in this report.

The contents of Spirit Lake in June 1982 were 260,000 acre-feet of water, and the lake water-surface elevation at that time was 3,457 feet. Overtopping of the June 1982 crest of the debris dam would occur at a water-surface elevation of 3,531.8 feet and contents of 501,000 acre-feet. Erosion could lower the crest of the debris dam an unknown amount during the next several years. Inspection of the surface of the lower slopes of the debris dam in June 1982 revealed the presence of several steep-walled, 30- to 40-foot-deep erosional channels in which headward cutting toward the debris dam crest appeared to be occurring.

Flood-routing assessments were made for several potential dam-break scenarios to determine peak discharges and their corresponding times of arrival at selected locations along the North Fork Toutle and Toutle Rivers.

APPROACH, CONDITIONS, AND ASSUMPTIONS

The U.S. Geological Survey General Purpose Dam-Break Flood Simulation (DBFS) model K-634, prepared by Land (1981), was utilized to compute and route potential clear-water flood hydrographs associated with Spirit Lake overtopping its debris dam. The DBFS model simulates a dam-break flood in two distinct parts. First, it computes the clear-water outflow hydrograph through the dam breach, and then it hydraulically routes the hydrograph through the downstream river valley. It is likely that large quantities of sediment would be eroded by and assimilated into a flood generated by a Spirit Lake breakout, thus resulting in potentially higher peak discharges. However, because a determination of the volume of sediment that might be entrained by such a flood was beyond the scope of this study, the computed clear-water hydrographs were routed unadjusted for the inclusion of sediment loads.

The primary parameters used in the DBFS model to compute the breach outflow hydrographs for this report were (1) Spirit Lake surface area-elevation table; (2) water-surface elevations at which breaches begin to develop; (3) breach shapes, bottom widths, and crest elevations; and (4) durations of breach development. Values for model parameters in items (2), (3), and (4) are inherently hypothetical because they describe possible future conditions. Therefore, a selected range of values was estimated for most parameters so that dam-break simulations using various combinations of these values would possibly bracket the potential range of floods that might occur.

The Spirit Lake surface area-elevation table was developed using 1:4,800-scale topographic maps with 10-foot contour interval, prepared photogrammetrically using aerial photography obtained in December 1980. A single breach shape, trapezoidal with horizontal-to-vertical side slopes of 0.5, and breach development durations of 0.25 hour and 1.0 hour were estimated on the basis of field observations of breaches that occurred at other, smaller lakes downstream of Spirit Lake. Breach bottom widths of 200 feet and 400 feet were estimated on the basis of field observations of existing erosional channels and measurements of crater widths on a 1:4,800-scale topographic map. A June 1982 field survey of the surface of the debris dam just downstream from the lake indicated that overtopping of the dam crest (existing at that time) would begin at a water-surface elevation of 3,531.8 feet. The lowest water-surface elevation for which a potential dam breach was investigated, 3,490 feet, was estimated on the basis of the 30- to 40-foot-deep erosional channels existing in the surface of the debris dam in June 1982. Dam-break simulations were computed for starting water-surface elevations of both 3,531.8 feet and 3,490 feet. Breach crest elevations of 3,490 feet and 3,470 feet were estimated on the basis of preliminary soil stability investigations and downstream channel slopes, respectively.

Model input data required for the hydraulic routing of the reservoir outflow hydrograph through the downstream river valley consisted primarily of initial base-flow conditions, river cross sections, channel roughness coefficients, channel contraction and expansion coefficients, and the hydraulic state of flow (subcritical or supercritical) within individual channel segments. Hydraulic parameter values used for routing the computed dam-break outflow hydrographs follow.

Initial base flows of either 1,000 ft^3/s or 10,000 ft^3/s were used for all computer runs. Twenty-three river cross sections were used to define channel geometry for the 52.4-mile reach from Spirit Lake (mile 0.0) to the mouth of the Toutle River (mile 52.4). The cross sections were obtained photogrammetrically using 1:9,600-scale aerial photographs taken during the summer of 1980. Channel roughness coefficients ranging from $n = 0.030$ to $n = 0.045$ were selected on the basis of field observations and engineering judgment. Channel contraction and expansion coefficients were estimated on the basis of comparison of successive pairs of channel cross sections. The hydraulic state of flow was estimated to be supercritical in the upper 19.5 miles of the North Fork Toutle River and subcritical in the remainder of the reach, on the basis of channel-slope determinations.

DAM-BREAK ANALYSES RESULTS AND CONCLUSIONS

Dam-break computations were obtained for 12 breach-development scenarios. Eight of the scenarios modeled breaches caused by overtopping of the June 1982 crest of the debris dam, while the other four modeled breaches resulting from overtopping of the debris dam at a possible future crest altitude of 3,490 feet. Equal numbers of scenarios, six each, were modeled for breach development durations of 0.25 hour and 1.0 hour. Peak discharges and times of arrival at selected locations for scenarios with breach development durations of 1.0 hour are presented in tables 1 and 2.

Model numerical instability was encountered when routing the breach outflow hydrographs computed for simulations with breach development durations of 0.25 hour. Comparison of breach outflow hydrographs for scenarios differing only in breach development duration revealed that peak discharges computed for durations of 0.25 hour exceeded those computed for durations of 1.0 hour by less than 12 percent. Had the streamflow routing simulation for scenarios with breach development durations of 0.25 hour not aborted, their breach outflow hydrographs, being more peaked, would have been expected to attenuate more rapidly than those for durations of 1.0 hour, thus decreasing the already minor differences between peak discharges of the simulations as the hydrographs were routed downstream. Therefore, results for dam-break scenarios with breach development durations of 0.25 hour are not included in this report.

Inspection of the results in tables 1 and 2 led to the following general conclusions:

1. Peak discharges computed for dam-break scenarios with breach crest widths of 400 feet are almost twice the magnitude of those computed for scenarios identical in all other respects, but with widths of 200 feet.

2. Peak discharges computed for breaches caused by overtopping of the debris dam at an altitude of 3,531.8 feet were generally found to be roughly five times greater than those caused by overtopping at an altitude of 3,490 feet, if the breaches had identical crest elevations and crest widths.

3. Decreases in peak discharge from Spirit Lake to the mouth of the Toutle River ranged from 16 to 26 percent for the scenarios modeled. This lack of significant attenuation is primarily due to the large volume and surface area of Spirit Lake (in excess of 360,000 acre-feet and 3,000 acres, respectively, for all scenarios modeled), which result in the continued discharge of high flows long after breach development is complete. The degree of attenuation is also minimized by the generally steep narrow valleys through which the North Fork Toutle and Toutle Rivers flow.

4. Elapsed time from beginning of breach development to arrival of peak discharges at the mouth of the Toutle River ranged from 4.3 to 7.4 hours for the scenarios modeled.

Prior to obtaining the model runs used for this report, some preliminary computer runs were made for breaches with crest widths of 100 feet and 500 feet and breach development durations of 0.25 hour, 1.0 hour, and 6.0 hours. Results of several of those runs were discussed at an interagency Spirit Lake flood hazard task force meeting on July 20, 1982. Subsequently, a "Situation Assessment and Recommendation" memorandum from the task force chairman to the forest supervisor, Gifford Pinchot National Forest, was released to the local news media. That memorandum contained, among other things, the results of two of the preliminary computer runs. Both runs were made for a full lake elevation of 3,531.8 feet, a breach crest elevation of 3,470 feet, and a breach development duration of 1.0 hour. The computed peak discharges at river mile 0.0 were 179,000 ft^3/s for the run with a breach crest width of 100 feet and 660,000 ft^3/s for the run with a breach crest width of 500 feet. These discharges are consistent with those presented in table 1.

To keep the computed results in proper perspective, it should be realized that none of the dam-break scenarios modeled may actually represent a "worst case" situation. However, since many of the computed peak discharges would probably result in catastrophic flooding, the results contained in this report should define a broad spectrum of potential Spirit Lake dam-break flood flows.

REFERENCE

Land, L. F., 1981, General purpose dam-break flood simulation model (K-634): U.S. Geological Survey Water-Resources Investigations 80-116, 101 p.

TABLE 1.--Summary of peak discharges and times of arrival at selected locations along the North Fork Toutle and Toutle Rivers for four breach scenarios caused by overtopping the 3,531.8-foot-altitude crest of the debris dam existing in June 1982

River miles below Spirit Lake	Case I[1]		Case II[2]		Case III[3]		Case IV[4]	
	Discharge (ft^3/s)	[5]Peak arrival time (hrs)	Discharge (ft^3/s)	[5]Peak arrival time (hrs)	Discharge (ft^3/s)	[5]Peak arrival time (hrs)	Discharge (ft^3/s)	[5]Peak arrival time (hrs)
0.0	312,000	1.0	170,000	1.0	558,000	1.0	310,000	1.0
19.5	296,000	1.9	162,000	1.8	515,000	1.6	287,000	1.8
35.0	280,000	3.2	151,000	3.6	474,000	2.8	268,000	3.2
[6]50.5	254,000	5.0	141,000	5.8	414,000	4.3	236,000	5.0

1 Case I. Final breach crest width equals 200 feet and final breach crest elevation equals 3,470 feet.
2 Case II. Final breach crest width equals 200 feet and final breach crest elevation equals 3,490 feet.
3 Case III. Final breach crest width equals 400 feet and final breach crest elevation equals 3,470 feet.
4 Case IV. Final breach crest width equals 400 feet and final breach crest elevation equals 3,490 feet.
5 Elapsed time since beginning of breach development.
6 River mile 52.4 is the mouth of the Toutle River.

TABLE 2.--Summary of peak discharges and times of arrival at selected locations along the North Fork Toutle and Toutle Rivers for two breach scenarios caused by overtopping the debris dam at an altitude of 3,490 feet

River miles below Spirit Lake	Case V[1]		Case VI[2]	
	Discharge ft^3/s	[3]Peak arrival time (hrs)	Discharge ft^3/s	[3]Peak arrival time (hrs)
0.0	55,600	1.0	104,000	1.0
19.5	52,800	2.0	96,300	1.9
35.0	50,000	4.4	88,600	3.8
[4]50.5	46,800	7.4	78,800	6.4

[1] Case V. Final breach crest width equals 200 feet and final breach crest elevation equals 3,470 feet.
[2] Case VI. Final breach crest width equals 400 feet and final breach crest elevation equals 3,470 feet.
[3] Elapsed time since beginning of breach development.
[4] River mile 52.4 is the mouth of the Toutle River.