June 29, 1993, Outburst Flood from Kidazgeni Glacier, Mount Spurr Volcano, Alaska

By Christopher J. Nye, William R. Hammond, Guy C. Tytgat, and Joseph M. Dorava

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ABSTRACT

A long, high-amplitude seismic signal caused by an outburst flood from the Kidazgeni Glacier occurred during the late morning of June 29, 1993. This was the longest continuous seismic signal recorded on the Spurr seismic network since the tremor episodes of October 2, 1992, and the earthquake swarm of November 9–10, 1992. The event was significant because visual analysis of helicorder records generated considerable concern that it might have been tremor premonitory to an eruption and because poor weather made direct observation of the Crater Peak vent of Mount Spurr impossible. The seismic signal was different from tremor both in the amplitude ratios between stations and in frequency content. This was not fully, or equally, appreciated by all those involved in the emergency response, and there was protracted discussion about whether or not the Alaska Volcano Observatory (AVO) should raise the level-of-concern color code. Fortuitously, a field crew was in the area during the increased seismicity, and they observed an outburst flood from the terminus of the Kidazgeni Glacier. This flood was the source of the seismicity.

INTRODUCTION

The Kidazgeni Glacier is a valley glacier that drains the southern part of the Mount Spurr amphitheater. The glacier is 1.5 to 3 km wide and about 7.5 km long (fig. 1). It averages 125 m in thickness and covers an area of about 21 square kilometers (R.S. March, oral commun.). It issues from the amphitheater on the east side of Crater Peak, the active vent of Mount Spurr volcano and the source of the 1992 eruptions (Eichelberger and others, this volume). It flows steeply from an altitude of about 2,135 m (7,000 ft) to about 900 m (3,000 ft) then spreads into a broad, flat lobe that ends at about 700 m (2,300 ft) elevation (fig. 1).

The Alaska Volcano Observatory currently maintains a local network of about 10 seismometers in the Mount Spurr area. Between 1981 and 1988, only 3 stations were maintained, and during that time the station closest to the terminus of the Kidazgeni Glacier was station CRP, 4 km to the north. From 1988 through 1992 the network density was increased. Station CKN, 1 km south of the Kidazgeni Glacier was installed in late 1991 (Power and others, this volume).

This report summarizes the local seismicity and event chronology of a small outburst flood that issued from the terminus of the Kidazgeni Glacier. The event was well recorded on local seismometers. Similar floods or seismic signals had not previously been noted at Mount Spurr, but they have occurred at other snow- and ice-covered volcanoes (see Brantley and Power, 1985; Driedger and Fountain, 1989).

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SEISMICITY

Seismicity associated with the flood began at 9:20 a.m. ADT (Alaska daylight time, Universal Time minus 8 hours) on June 29,1993, with an abrupt increase in amplitude of about two times the background level at station CKN (figs. 1, 2, 3). Within about 3 min-

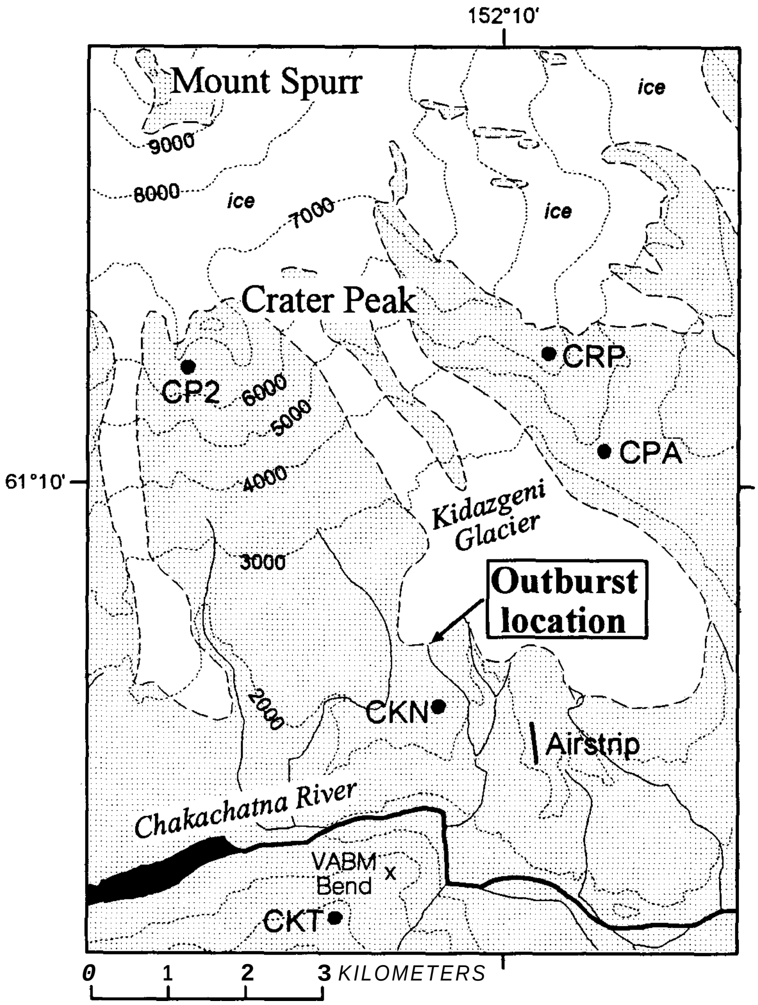

Figure 1. Geography of the Kidazgeni Glacier area of Mount Spurr volcano, Alaska, showing outburst flood location, location of seismic stations (CP2, CRP, CPA, CKN, and CKT), and geographic features referred to in the text. Contour interval 1,000 feet.

utes the seismic signal had begun clipping (some part of the seismometer and telemetry system was saturated). Seven minutes after the initial onset, the amplitude abruptly decayed to nearly background level, where it remained for about 8 minutes. At 9:36 a.m. ADT, a second stronger and longer seismic pulse began (figs. 2, 3). By about 10:11 a.m. ADT, seismicity at CKN was back to two times background level. It remained at this level for about another 9 minutes, when there was a third seismic pulse similar in duration to the initial pulse. Unlike the initial pulse, which stopped abruptly, the third pulse decayed over a period of about 10 minutes. The background seismicity level remained slightly above the pre-event level for the next day or so. The observed frequency of the seismic signal peaked at 4 to 6 Hz, and it had a broad high-frequency tail extending out to about 16 Hz (fig. 4). This frequency content was distinct from the June 26, 1992, pre-eruptive tremor as recorded at station CKN, which had lower frequencies (2–4 Hz) and did not have much energy above 5 Hz. Following the main seismic event on June 29, an increased number of discrete, short duration events were recorded primarily at station CKN. These persisted for a few days (figs. 2, 5).

Other seismic stations recorded the seismicity associated with the flood, although the peaks in amplitude were shifted in time (fig. 3). These times reflect more than merely greater distance from the source. Instead, they record either a migrating source or the onset of the most energetic seismicity, which could only be sensed at more remote stations. An unequivocal choice between these two possibilities cannot be made because station CKN had clipped so the time of maximum seismic intensity there could not be determined. However, we favor the onset of more energetic seis-

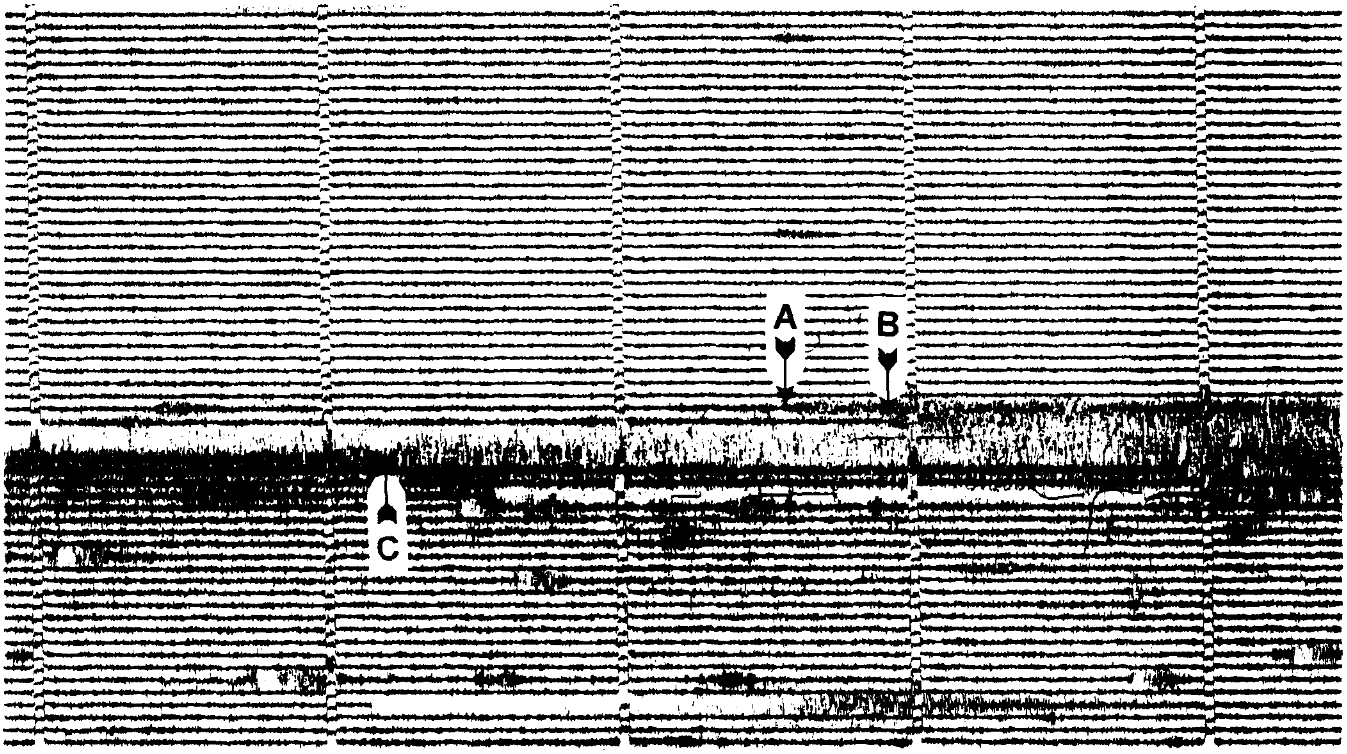

Figure 2. Part of the June 29, 1993, helicorder record for seismic station CKN, (Mount Spurr volcano, Alaska) showing the initial (A), second (B), and third (C) onsets of high-amplitude seismicity and post-outburst discrete events. The background noise preceding the outburst had been typical of station CKN since early June. Tick marks are 1 minute apart.

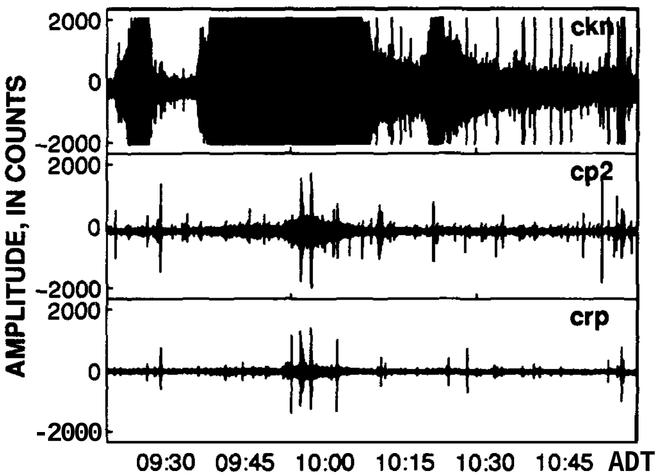

Figure 3. Digital seismic records of the outburst flood at seismic stations CKN (top), CP2 (middle), and CRP (lower) located on or near Mount Spurr volcano, Alaska. Note high intensity and early onset at station CKN.

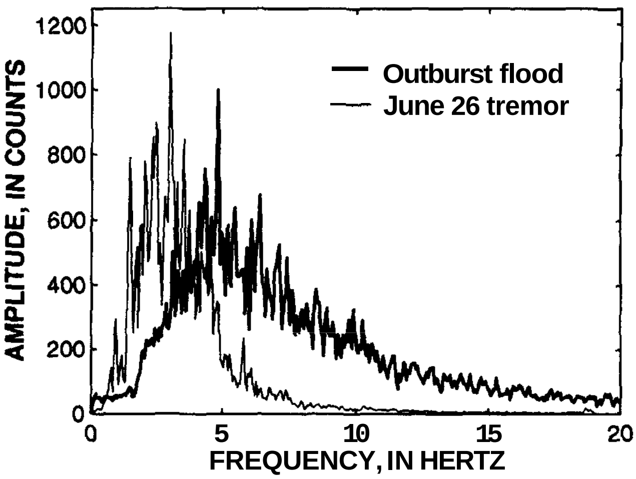

Figure 4. Frequency content of the June 29, 1993, outburst flood and June 26, 1992, pre-eruptive tremor as recorded at station CKN. Each spectrum is constructed from several 10-second segments, which have been stacked to reduce noise.

micity as a possibility. A plot of the envelope of seismicity (not shown) suggests that the maximum energy was released at the time the largest signal was recorded at stations CP2 and CRP.

Station CP2 showed an increase in seismic activity beginning at 9:38 a.m. and ending about 10:05 a.m. ADT. The frequency content was broadly distributed, extending from 2 to greater than 20 Hz with no distinct spectral peaks (fig. 6). The signal-to-noise ratio was low, but the signal exceeded the noise for all but the very lowest and very highest frequencies. Station CRP showed an increase in seismic activity beginning at 9:52 a.m. ADT and ending about 10:05 a.m. ADT (fig. 3). The frequency content of the signal was narrow, peaking at 2 Hz, but had a broad, very low-amplitude tail extending to higher frequen-

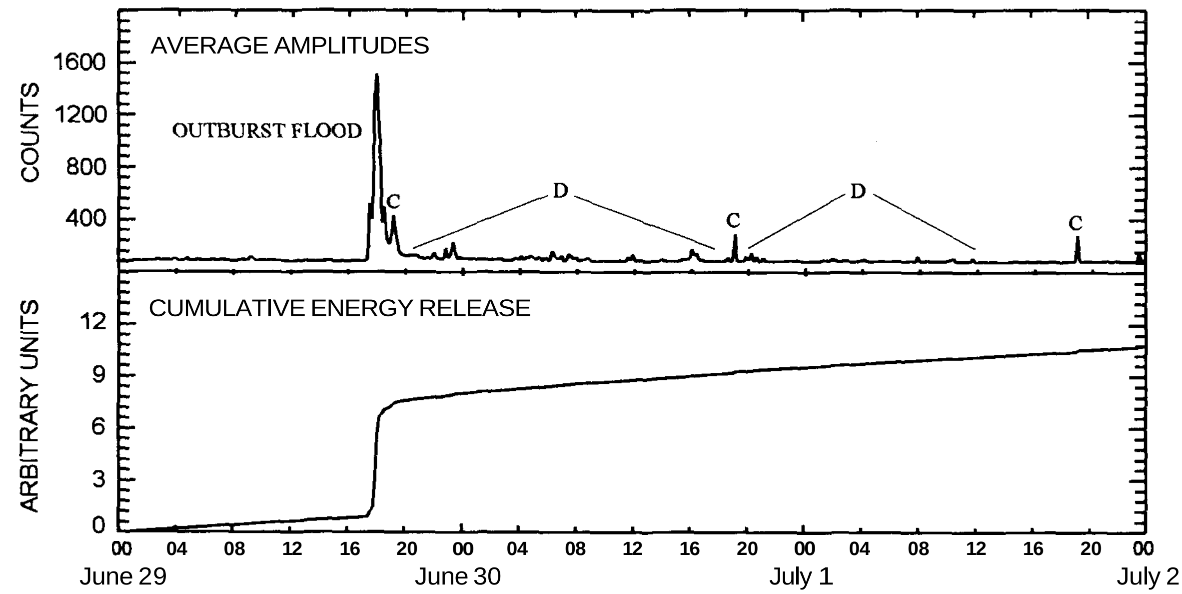

Figure 5. RSAM plots of the outburst flood and succeeding discrete events as recorded at seismic station CKN (located on Mount Spurr volcano, Alaska). In upper plot, discrete events are marked "D" and calibration pulses "C." Upper plot is the average amplitude in counts; lower plot is cumulative energy release in arbitrary units. The graph starts on June 29, 1993, and runs through July 1, 1993. Universal time (intermediate ticks on horizontal axis) expressed in 4-hour increments.

cies (fig. 7). The signal-to-noise ratio was low, however the signal exceeded noise below about 7 Hz. Note that the spectra from stations CP2 and CRP have amplitudes two orders of magnitude lower than those from station CKN. Some aspects of the frequency spectra, particularly high-frequency attenuation, may be artifacts of signal dampening associated with the low energy and greater distances between stations CP2 and CRP and the source and station CKN and the source. Additionally, the low signal-to-noise ratio for these two spectra may significantly reduce the meaningfulness of these data. The June 29 seismic activity at Mount Spurr volcano resembled tremor seen prior to past eruptions with the critical differences that the most energetic signal was not recorded at the station closest to the vent and the frequency content was higher at the station with the highest amplitude signal (CKN).

FIELD OBSERVATIONS

During the time of increased seismicity, a field party consisting of personnel from AVO, the Cascades Volcano Observatory (CVO), and Carnegie Mellon University was attempting to reach Crater Peak for a reconnaissance in preparation for a robotic mission scheduled for 1994. They approached Crater Peak from the east at about 10:05 a.m. ADT. The cloud base was at about 1,200 m. The field party was informed of the sustained seismicity by AVO Anchorage and landed at the airstrip 1.5 km east of station CKN (fig. 1) to obtain more information because internal radio communication in the helicopter was not working properly. At the airstrip the field crew was informed of the nature of the seismicity and the concern that it might be tremor premonitory to an eruption. The field crew moved to VABM Bend (fig. 1) by 10:30 a.m.

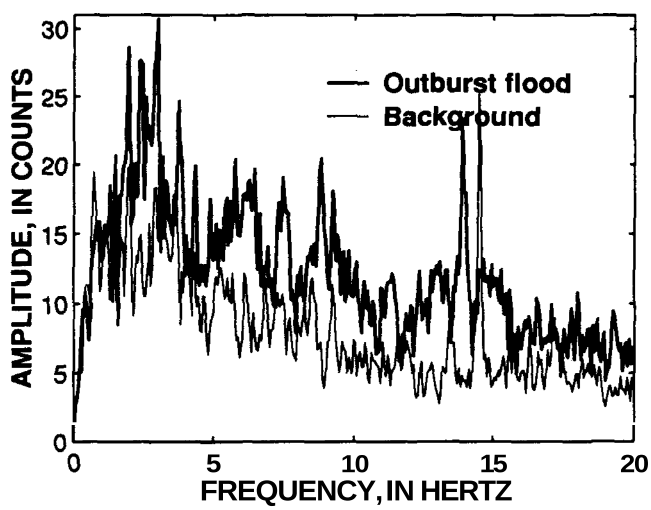

Figure 6. Frequency content of the June 29, 1993, outburst flood from Kidazgeni Glacier, Alaska, as recorded at seismic station CP2 on Mount Spurr volcano. Note extremely low amplitude compared to signal recorded at station CKN (see fig. 4).

ADT. When leaving the airstrip those members of the field crew familiar with the Mount Spurr area noted that the creek flowing between the airstrip and station CKN (informally called Kidazgeni Creek here) was in flood with dark brown water that was heavily laden with sediment. The water level was higher than had ever been observed previously by those in the field party. Where Kidazgeni Creek entered the Chakachatna River the flow was large enough that mixing was immediate across the entire width (80–100 m) of the Chakachatna River. Below the mouth of Kidazgeni Creek, the Chakachatna River was the same shade of dark brown as Kidazgeni Creek. Above Kidazgeni Creek the Chakachatna River was its typical milky blue-green. We estimate that the flow out of Kidazgeni Creek must have been a few tens to several tens of percent of the total flow of the Chakachatna River to so completely and immediately dominate the river's color.

The field crew remained at VABM Bend observing Kidazgeni Creek, waiting for a change in the seismicity, and waiting for the clouds to lift to allow access to Crater Peak. By 12:25 a.m. ADT the flow in Kidazgeni Creek had subsided enough to expose freshly cut and collapsing stream banks with cutbanks on the order of 1 m high. The field crew conducted an aerial reconnaissance of Kidazgeni Creek and lower Kidazgeni Glacier. Flow into the Chakachatna River was reduced to the point that the muddy brown flood water no longer dominated the Chakachatna River at the confluence with Kidazgeni Creek. Instead, flow from Kidazgeni Creek influenced about one quarter of the width

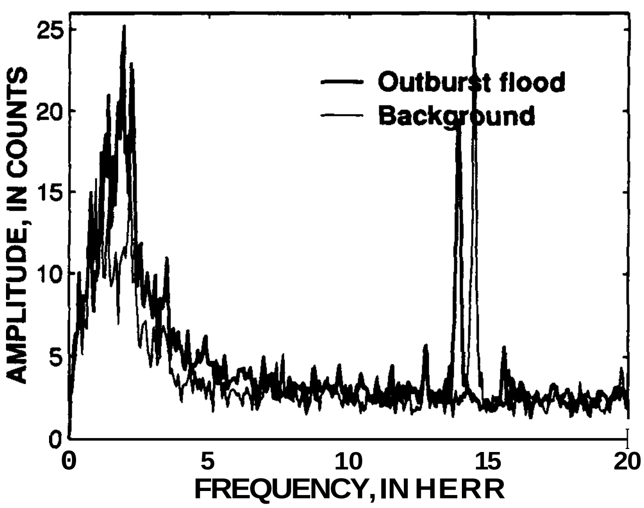

Figure 7. Frequency content of the June 29, 1993, outburst flood from Kidazgeni Glacier, Alaska, as recorded at seismic station CRP on Mount Spurr volcano. Note extremely low amplitude compared to signal at CKN (*see* fig. 4). Signal-to-noise ratio is small, but signal exceeds noise between about 1.5 and 7 Hz.

of the Chakachatna River, and it followed the northeastern bank downstream for a few hundred meters before complete mixing. After mixing with the reduced discharge from Kidazgeni Creek, the Chakachatna River was intermediate in color between the dark chocolate brown of Kidazgeni Creek and the milky blue-green of the upper Chakachatna River. The field crew also noted a new stream exit in the western terminus of the Kidazgeni Glacier (fig. 1) surrounded by newly broken ice blocks. It was from this new exit that the dark brown flood waters were issuing. A small superglacial stream a few tens of meters to the west was flowing clear, and another subglacial stream several tens of meters to the east was the typical milky blue-green of glacial streams. The field crew proceeded up glacier to about the 1,500 m level looking for major changes to the surface of the glacier but saw none. There is no indication that the outburst was generated by rapid draining of a superglacial lake. Instead the water storage must have been englacial or subglacial. The glacier in this area is heavily crevassed with a thick cover of debris and 1992 tephra. The field crew returned to the airstrip to observe Kidazgeni Creek and wait for better weather. A small rock slide was correlated with one of the discrete seismic events recorded by station CKN. By 3:50 a.m. ADT the ceiling had lifted to within a hundred meters of the low spot on Crater Peak rim and the field crew flew up along the southern flank of Crater Peak hoping for at least a view into the crater. The ceiling was solid and below the lip of the crater so the field crew returned to Anchorage.

Periodic field investigations of the Kidazgeni Glacier surface were made throughout the 1993 field season to search for evidence that a single subglacial cavity containing the water had drained. However, no surface collapse features were found.

DISCUSSION

On June 29, 1993, subglacial water burst from a small opening in the terminus of Kidazgeni Glacier and rushed down the steep slopes of Crater Peak to the Chakachatna River. This outburst flood was well recorded seismically and confirmed by field observations. Seismicity at the station nearest the outburst location (CKN, 1 km south) was distinct from volcanic tremor in its high frequency content (peaking at 5 Hz compared to 3 Hz tremor) and high-frequency tail extending to greater than 20 Hz (fig. 4). The distinct high-frequency signal was greatly attenuated by the time outburst seismicity was recorded at stations more distant (but still within 5 km of the creek). Similar broadband high-frequency seismicity was also observed during floods and lahars at Mount St. Helens, Redoubt

Volcano, and Mount Pinatubo (Brantley and Power, 1985; Dorava and Meyer, 1994; Bautista and others, 1991). The characteristic frequency of flood events has been recognized by developers of acoustic flow monitoring instruments, which have been used to remotely detect lahars (Hadley and LaHusen, 1991). The increase in discrete events after the June 29 outburst was also recorded most strongly at station CKN, and presumably it reflects settling of the glacial ice after withdrawal of englacial or subglacial water. It is not uncommon to have large quantities of water stored in or under glaciers, especially those on active volcanoes. Post and Mayo (1971) noted that "glaciers with no visible lakes may present unusual flood hazards" and that there is "a common association of glacier outburst floods with glacier-clad volcanoes."

The total discharge of the flood is not precisely known because no flow rate measurements were made during the event and no channel slope and cross-section measurements were made after the event. However, based on the complete and immediate mixing of Kidazgeni Creek and the Chakachatna River, field observers estimated that peak flow from Kidazgeni Creek was a few tens of percent of the total flow of the Chakachatna River. Average June, July, and August flow of the Chakachatna River was about 280 m^3/s during the period 1959–1972 (U.S. Geological Survey, 1973). If the outburst flood of June 29, 1993, produced a sustained discharge of 20 to 30 percent of this flow during the 66 minutes of seismic shaking at station CKN, then the total flood volume would have been 220,000 to 330,000 m3. This may underestimate the total volume because field observers noted that Kidazgeni Creek flow remained at least somewhat elevated after seismicity at station CKN returned to near-background levels. The volume of this flood is about four orders of magnitude less than more commonly known outburst floods such as the Grimsvotn jokulhlaups in Iceland (Drewry, 1986). If this volume of water was released from a reservoir on the surface of the glacier it would require a pond about 100 m in diameter and 10 m deep. No such pond was seen on the surface of the Kidazgeni Glacier at any time during the years of periodic observations prior to the outburst, thus the outburst must have come from englacial or subglacial storage.

The magnitude of this outburst flood is difficult to compare with normal run-off from the glacier because of the scarcity of meteorological data, streamflow data, and comparable basin-characteristic information from similar glacier streams. The probable summer flow from the Kidazgeni Glacier was estimated by dividing the average summer discharge of the Chakachatna River at the gauging station (280 m^3/s; U.S. Geological Survey, 1973) by the 2,900 km^2 area of the basin providing that flow, resulting in a unit discharge of 0.0966 $m^3/s/km^2$. We compare this to the discharge of two unglaciated basins 125 km to the northeast, which average 0.0366 $m^3/s/km^2$ and conclude that about 60 percent of the flow of the Chakachatna River is contributed by the 30 percent of the basin covered by glaciers. This analysis suggests that the average discharge from glaciers in the Chakachamna Lake basin is 0.20 $m^3/s/km^2$. The Kidazgeni Glacier is about 21 km^2, and thus should have an average runoff of about 4.3 m^3/s, making the peak outburst flood discharge of 70 m^3/s about 16 times the mean summer runoff. The estimated flood volume corresponds to about one day of average runoff for the entire glacier at 4.3 m^3/s. We caution that there may be substantial errors in estimating both the flood volume and typical runoff from the Kidazgeni Glacier. We believe, however, that the figures presented here illustrate at least the order of magnitude of volumes involved.

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