Jökulhlaup in the Wind River Mountains, Shoshone National Forest, Wyoming

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A jökulhlaup burst from an ice-dammed lake at the head of Grasshopper Glacier in the Fitzpatrick Wilderness of Wyoming's Wind River Range during early September 2003. The 12-hectare lake drained an estimated 3.2 million cubic meters of water, down slope, underneath the glacier, and down tributary valleys into the Wind River valley. The outburst flood was recorded at a USGS gage (06221400; drainage area 245 km^2) on the Dinwoody River approximately 33 km downstream from the ice-dammed lake. Jökulhlaups can be triggered by volcanic, seismic, and meteorologic events, and perhaps by climatic warming. Satellite images of the Wind River Mountains show dramatic recession of the glaciers since 1986. Work by Naftz et al. (2002) on the Upper Fremont Glacier (10.5 km south of Grasshopper Glacier on the Continental Divide) shows a warming trend and temperature increase of 3.5°C at high elevations over the past fifty years. It is likely that the Grasshopper Glacier jökulhlaup was triggered by local conditions within the glacier and the outburst lake created by this climatic warming trend. Reconnaissance surveys in the summer of 2004 characterized the geomorphic effects and addressed the hazards associated with the jökulhlaup. Five distinct sedimentation patterns formed in reaches of the river downstream from the glacier. Outburst floods in the Wind River Range will probably recur in the near future, as the glaciers continue to recede.

Keywords: *channel geomorphology, flood processes, geology/geomorphology, glaciation, hydrologic processes, sedimentation, streamflow, woody debris*

Background

A jökulhlaup, or glacial outburst flood, burst from an ice-dammed lake at the head of Grasshopper Glacier in Wyoming's Wind River Range during early September 2003. The 12-hectare lake drained an estimated 3.2 million cubic meters of water downslope, underneath the glacier, and down tributary valleys into the Wind River valley. The outburst flood was recorded at a USGS stream gage (06221400; drainage area 245 km^2) approximately 33 km downstream from the ice-dammed lake. During the period 1956-2001, annual peak snowmelt flow at the gage averaged 23 cubic meters per second (range 14-42 cubic meters per second). On 9 September 2003, the gage recorded a peak of 36.5 cubic meters per second, which rose from a base flow of 7 cubic meters per second on 6 September (Figure1).

Grasshopper Glacier lies on the Continental Divide between high-level erosion surfaces and the eastward-facing cirque walls of the mountain front. The glacier, which flows from south to north, drops 2.8 km from approximately 3647 m down a slope of 0.11 to its snout at 3435 m elevation. Grasshopper Glacier is presently about 2.5 km wide and covers approximately 364 hectares. The catchment of the outburst lake is at most 2.8 km^2, and only a small remnant of the glacier remains in the cirque above the lake. Ice at the margin of the lake is 18-21 m thick. (Figure 2)

The Grasshopper Jökulhlaup

The outburst flood entrained subglacial sediment as it flowed for 2.8 km beneath Grasshopper Glacier. The sediment-laden flood then followed the steep, narrow valley of Grasshopper Creek to the Downs Fork and its confluence with Dinwoody Creek. Here, where the valley widens in a broad u-shaped glacial valley, the flood ponded in an ephemeral lake at the low gradient Downs Fork Meadows 13 km downstream. The flood then continued to step down the valley for another 23 km, to Mud Lake, the gage site, the Dinwoody Lakes, and on to the Wind River. Along most of this route, the flood

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Figure 1. Grasshopper Glacier is located in the Fitzpatrick Wilderness, on the Shoshone National Forest, in the Wind River Range about 30.5 km south of Dubois, Wyoming. The USGS stream gage site on Dinwoody Creek is located at the eastern margin of the watershed on the Wind River Indian Reservation. Dinwoody Creek crosses Wyoming Hwy. 287 downstream of the gage site, and is tributary to the Wind River. Map base is USGS topographic series Thermopolis Sheet 1:250,000.

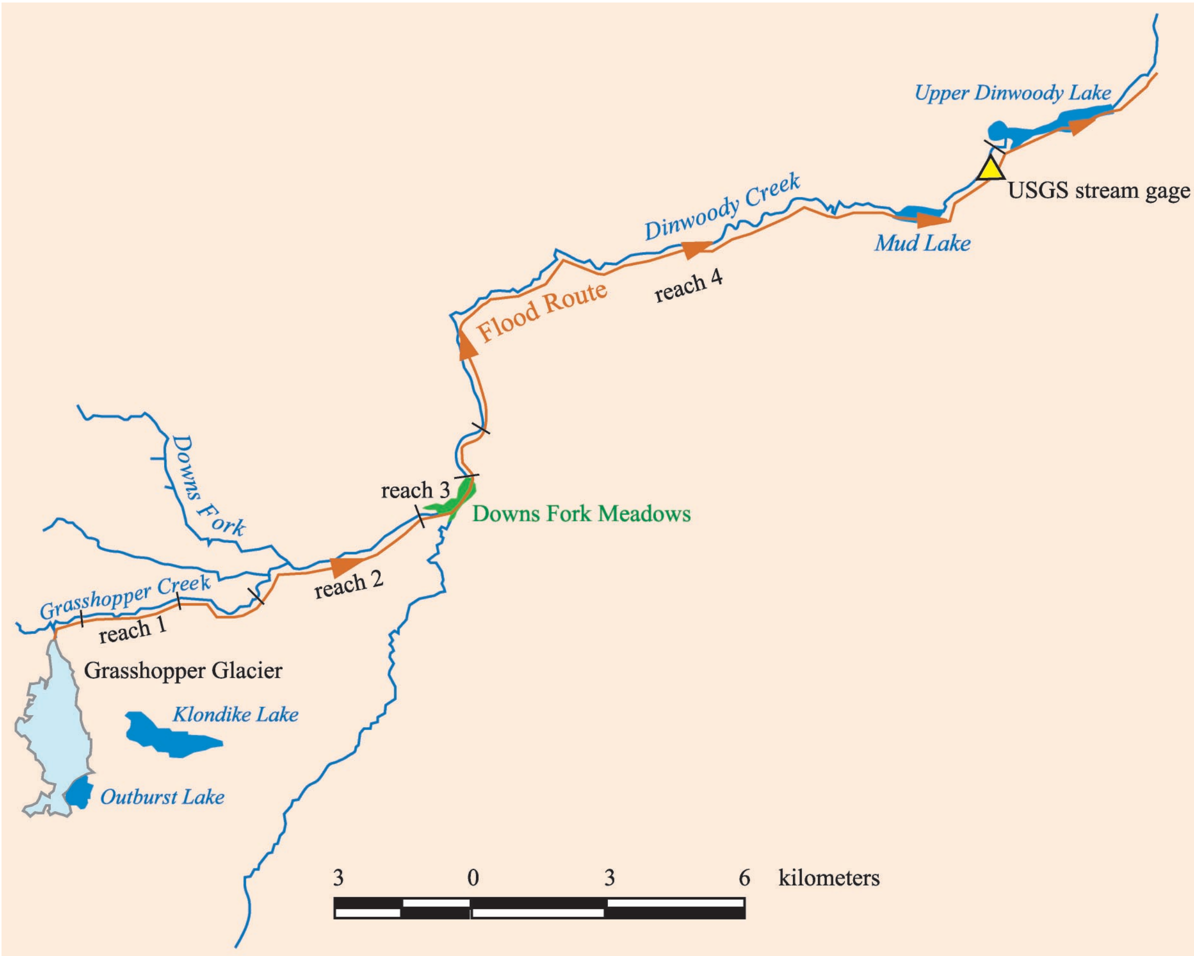

Figure 2. Ice-dammed lake that drained from head of Grasshopper Glacier. The view is to west. The lake drained beneath glacier to the north, and flooded to the north then east down the drainage of Grasshopper Creek, to Downs Fork Creek, and to Dinwoody Creek.

traversed glaciated terrain of granites, migmatites, and gneiss. Paleozoic sedimentary rocks crop out near Mud Lake.

Aerial surveys about two weeks after the flood showed the jökulhlaup had deposited bedload in apparently braided channels from the head of Grasshopper Creek down to the confluence with the Downs Fork. Floodwaters scoured the abutments of the Downs Fork Bridge, then overtopped the bridge and deposited large woody debris, creating a debris jam on the bridge. Suspended sediment roiled through the ephemeral lake at Downs Fork Meadows. When the lake level subsided, 0.6-1.5 m of granitic silty sand were deposited over an area of approximately 28 hectares. Suspended sediment transport continued down Dinwoody Creek, where 1-meter-high standing waves were observed. The creek avulsed from its pre-flood meandering course through the meadow, creating numerous overflow channels, and filling the pre-flood channel with sediment. Downstream nearly 33 km from the outburst lake, Mud

Lake practically filled with sediment. Fine sediment was carried into the Dinwoody Lakes, and was still present in Dinwoody Creek (where it crosses Wyoming Highway 287) at unusually high levels in mid-November 2003.

Jökulhlaups have been attributed to volcanic, seismic, and meteorologic triggers (Cenderelli and Wohl 2001, 2003; Walder and Costa 1996). The warmer summers and shorter, warmer winters likely to accompany climatic warming may also increase the incidence of jökulhlaups as glacial ice melts and thins more rapidly. No direct correlation was found between regional meteorologic or seismic events and the Grasshopper Glacier jökulhlaup, but the jökulhlaup did occur during unseasonably warm weather in the fifth year of a severe regional drought.

The rapid recession of glaciers worldwide is well documented. Satellite images of the Wind River Range (courtesy of Sky Truth, John Amos) show particularly dramatic recession since 1986. Work by Naftz et al. (2002) on the Upper Fremont Glacier, 10.5 kilometers from Grasshopper Glacier, indicates a warming trend and temperature increases of 3.5 degrees Celsius at high elevations in this region during the past 50 years. It is hypothesized that accelerated warming in the high elevation areas of the Wind River Range, as documented in the ice-core record, caused melting and recession of the glaciers, producing increased meltwater which eventually filled the ice-dammed lake perched on the bedrock floor above Grasshopper Glacier, and caused the glacial outburst flood (Naftz et al. in press).

Field reconnaissance surveys conducted in summer 2004 recorded the geomorphic effects of the jökulhlaup as the flood eroded, transported, and deposited sediment and shaped the river and its valley along the flood route. From the draining of the ice-dammed lake (Figure 2) and subglacial entrainment of sediment, five distinct

Table 1. Summary of characteristics of studied reaches of Grasshopper Creek.

Reach	Distance Below Glacier (km)	Average Valley Gradient	Figure
1	4.2 - 6.1	0.045	3
2	8.2 - 13.2	0.025	4
3	13.2 - 15.3	0.013	5
4	16.7 - 21.2	0.025*	-
5	32 - 38.6	NA	-

***in depositional areas**

sedimentation patterns were documented in reaches downstream from the glacier. These five reaches are characterized in a downstream direction by: 1) "outwash" deposition of expansion bars; 2) log jams, stream bed aggradation and overbank deposition; 3) channel avulsion and aggradation, and deposition from ponding in an ephemeral lake; 4) in-channel depositional filling of riffles and pools; and 5) silt and clay deposition in lakes and irrigation systems. Also in a downstream direction, median grain size progressively decreased from boulders to cobbles at the expansion bars, to gravels, sands, silts and clays toward the gage site.

Outwash deposition of expansion bars occurred in the most upstream reaches (Table 1) of Grasshopper Creek (Figure 3; Reach One: 4.2 km to 6.1 km; distance measured from outlet of outburst lake at head of the glacier). Valley slope averages about 0.045. Bar deposition spread out across the entire valley bottom, up to 0.2 km wide and 1.4 m high. Log jams, stream bed aggradation, and overbank deposition occurred in a lower-gradient reach with 0.025 average slope (Reach Two: 8.2 km to 13.2 km distant from the outburst lake). Sixteen log jams were recorded that persisted in the valley at the time of the survey. The largest

Figure 3. Expansion bars deposited by flood in upper reaches of Grasshopper Creek. The view is upstream.

Figure 4. One of the many log jams on the Downs Fork. The view is downstream

log jam was at a maximum up to 12 m wide down the length of channel, 35 m across the width of channel, and up to 3.5 m high from the channel bed (Figure 4). At the Downs Fork bridge, large woody debris had been removed in order to "save the bridge". Channel avulsion and aggradation, log jams, and deposition of suspended load in an ephemeral lake occurred in the Downs Fork meadow area, with 0.013 average slope (Reach Three: 13.2 km to 15.3 km) (Figure 5). In-channel depositional filling of riffles and pools occurred below Dinwoody Falls, to below Shangri-La Meadows, and on to the lower reaches of the Dinwoody valley (Reach Four: 16.7 km to 21.2 km and beyond). Slopes averaged 0.025 at depositional areas of these reaches. Silt and clay deposition in lakes and irrigation systems occurred in the lower reaches of the Dinwoody valley at Mud Lake, the Dinwoody Lakes (Reach Five: 32 km to 38.6 km), and irrigation canals and ditches that traverse the lower Dinwoody River to the Wind River floodplain.

Conclusions

No known fatalities, and only minor structural damage to the Downs Fork bridge and disruption of the Downs Fork outfitter camp, occurred in the Fitzpatrick Wilderness as a result of the jökulhlaup. There is an increased flood risk in the upper reaches of the flood area due to aggradation of stream channels. Log jams that formed during the flood created significant geomorphic effects on the river valley. The flood produced a local impact on irrigators of the upper Wind River Indian Reservation, not only due to the siltation of irrigation ditches, but also due to the diminishing glacial reservoirs which the irrigators rely on for late-season irrigation. It is likely that continued warming and melting of glaciers in the Wind River Range will result in future and perhaps more frequent outburst flood events.

Figure 5. Aerial view of Downs Fork Meadows in late September 2003, showing extent of flood deposition in ephemeral lake, channel avulsion, and overbank flows. Left is downstream.

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