David R. Butler, Department of Geography, University of Georgia, Athens, Georgia 30602

Snow Avalanche-Dams and Resultant Hazards in Glacier National Park, Montana

Abstract

Snow avalanches form natural dams to creek and river flow in Glacier National Park, Montana. Dams are produced primarily by dense wet snow avalanches. Because such dams are unstable and so pose a serious threat to downstream habitats, I analyzed them in areas of Glacier National Park. Dam formation occurs under conditions of either zonal or meridional flow. Dams may be deposited during winters of high avalanche frequency, but such conditions are not essential. Temporary reservoirs have been impounded by avalanche-dams, causing stream impoundment and inundation of highways. Calculated potential maximum flood discharges illustrate a hazard of serious proportions, in some cases exceeding all but one known historical spring flood. Three areas in the Park are of special concern because of the history of avalanche-dam development across transportation lines. Future avalanche-dams and resultant outburst floods could damage roadways and a major bridge.

Introduction

Natural dams form in many ways. Barriers can be formed by landslides, ice or snow, glacial moraines, volcanic eruptions, fluvial deposition, eolian deposition, coastal sedimentation, and by organic accumulations (Costa and Schuster 1988). Most natural dams are inherently unstable, and dam failure can lead to widespread devastation and loss of life (Costa 1988).

Snow avalanches form natural dams in alpine environments around the world; outburst floods and associated devastation caused by failure of snow avalanche-dams have been reported from the Andes of Argentina (King 1934), the European Alps (Allix 1924, Peattie 1936, Tricart *et al.* 1961), the northern Scandinavian region (Rapp 1960), and the Torlesse Range of New Zealand (Ackroyd 1987). One such tragedy was described by Peattie (1936, p. 59): "On the 20th of February, 1720, the Swiss village of Obergestelen was destroyed and 84 of its 200 inhabitants were killed by an avalanche which leaped an intervening forest and wrecked one-third of the village.....The snow from the avalanche blocked the river Rhone, which quickly cut through it and then flooded a portion of the settlement." The failure of the avalanche dam and subsequent flooding exacerbated an already desperate situation, and occurred during recovery operations.

Despite the widespread occurrence of snow avalanches and avalanche accidents in Canada and the United States (Stetham and Schaerer 1979, 1980; Schaerer 1987; Williams and Armstrong 1984), there has been very little focus on snow avalanche-dams and resultant floods in the mountainous regions of North America; exceptions include the study by Mokievsky-Zubok (1975) in an uninhabited portion of the Coast Mountain Range of British Columbia, and the recent work of Campbell (1988) in the vicinity of McBride and Valemount in the Robson Valley of British Columbia. As population pressure and mountain developments continue throughout the North American west, it becomes increasingly important to identify areas susceptible to potential flooding from snow avalanche-dam outbursts (Campbell 1988). The purpose of this paper is to describe the hazards associated with avalanche-dam failure and also to document the geographic extent and climatic characteristics responsible for the formation of snow avalanche-dams in a typical North American alpine environment.

Snow Avalanches and Avalanche-Dams

Two major types of snow avalanches are recognized in avalanche classifications: the slab avalanche, where a large area of cohesive snow across a slope begins to slide all at once; and loose snow avalanches, which start at a point or over a small area and increase in size as they descend (LaChapelle 1985, p. 19-20). Loose snow avalanches are frequently subdivided into dry snow and wet snow avalanches. Of these three types (slab, dry loose, and wet loose snow), wet snow avalanches are the primary mechanism for creating snow avalanche-dams. Slab avalanches frequently disintegrate into smaller masses upon descent (LaChapelle 1985), and dry loose snow avalanches frequently do not possess sufficient cohesion to act as efficient dams. The wet snow avalanches, because of their weight and density, possess enough strength to temporarily dam creeks and rivers and create short-term natural reservoirs.

The period of time in which an avalanche-dam may exist will vary with the size, cohesiveness, and density of the snow deposit. Estimates of longevity of known avalanche-dams range from about one hour (Allix 1924) to over eight days (Mokievsky-Zubok 1975). One example of the density of a wet snow deposit which formed an avalanche-dam in the present study area is provided by Martinelli (1984). He examined an avalanche deposit which temporarily dammed the Middle Fork of the Flathead River in northwestern Montana. The deposit, examined four days after deposition, still had many large air spaces within and was composed largely of wet icy balls of snow. Debris density, measured with a Federal snow sampler, averaged 414 ± 37 kg/m^3 for eight samples.

The Study Area

Glacier National Park, located in the Rocky Mountains of northwestern Montana, is typical of many North American alpine areas. Increasing winter usage of the Park for recreational purposes occurs in heavily glaciated terrain prone to snow avalanches. Major transportation links also pass through this avalanche-prone terrain (Figure 1). U.S. Highway Number 2 (US2) is a major east-west transportation link in Montana which parallels the Middle Fork of the Flathead River along the southernmost boundary of the Park (Figure 1). A daily average of at least 714 vehicles use this highway (Butler 1986b), which was completed through this area in 1930. The only road that penetrates deeply into, and crosses, the Park is Going-to-the-Sun (GS) Road, a narrow, two-lane road which was opened to traffic in 1933. GS Road usage is seasonal, typically open only from late May to late October. Avalanche potential is high along GS Road in winter and spring, and the avalanche paths which occur in this area penetrate through the mature forest to impinge upon the valley bottom (Butler 1980). McDonald Creek is a major permanent stream that parellels GS Road for about 10 km above the head of Lake McDonald.

The peak snow avalanche month in the Park is February, with secondary maxima in January and March (Butler 1986a). Meteorological triggering mechanisms for avalanches there include: 1) heavy snow, 2) heavy snow followed by a rapid rise in temperature to above freezing, 3) a rise in air temperature to above freezing without precipitation, and 4) rain in association with above-freezing temperatures (Butler 1986a). Avalanche types present along the major transportation links include dry loose snow avalanches, wet snow avalanches, and slab avalanches (Butler and Malanson 1985a, 1985b, Butler 1986a, 1986b). Wet snow avalanches are the most common type to affect the major roads, with 80 percent of 223 studied avalanches resulting from weather conditions with temperatures above freezing (Butler 1986a, p.82). Wet snow avalanches are also the predominant type of avalanche in other regional study areas such as the Kananaskis region of southwestern Alberta (McPherson *et al.* 1984). Because wet snow avalanches are the primary avalanche type in the area, it is not surprising that a hazard exists from avalanche-dams and associated outburst floods.

Methodology

In recent studies of avalanche accidents in Glacier National Park, Butler (1986a, 1986b) compiled statistics on the location and nature of snow avalanche incidences for the 75-year period 1910-1985. Data sources included Glacier National Park Ranger daily logbook entries and monthly summary reports (Unpublished Monthly Ranger Report[1]); U.S. Government monthly weather summaries for all years since 1910; unpublished letters, files, photographs, and slides on file in the Glacier National Park library; information from the Montana Department of Highways; and all December through May issues, 1946-1988, of the *Hungry Horse News,* a local weekly newspaper published since 1946 in Columbia Falls, Montana. This newspaper provides local accounts of avalanche occurrences of a size or timing significant enough to hinder local transportation and impact local tourism.

This study uses the same historical data set, and is supplemented by additional sources covering the winters of 1985-1988. Information was recorded on the location of snow avalanche dams, weather conditions associated with the avalanching, and the type of avalanche which formed

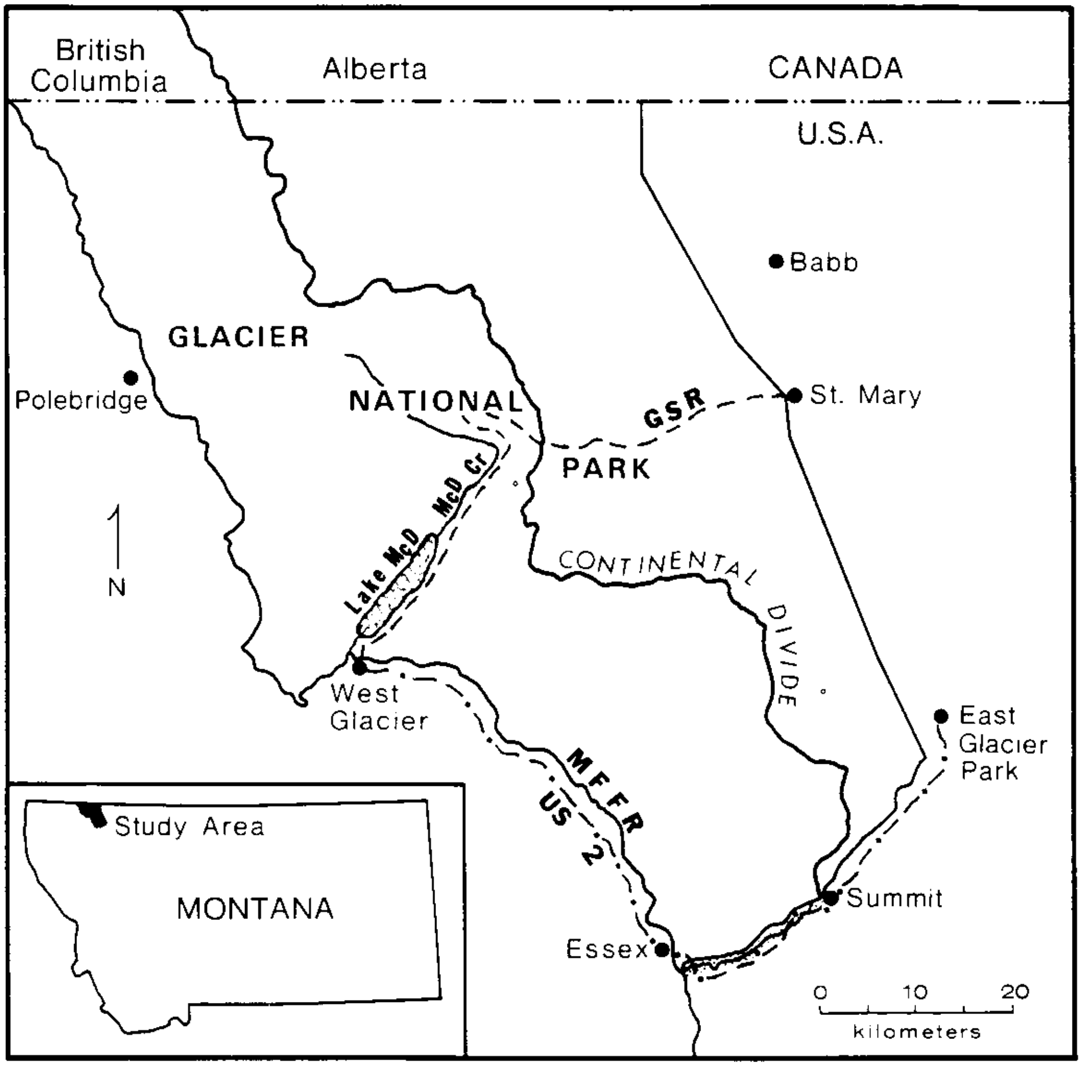

Figure 1. Locations susceptible to avalanche-dam hazards, Glacier National Park, Montana. Abbreviations as follows: GSR, Going-to-the-Sun Road; US2, U.S. Highway 2; MFFR, Middle Fork of the Flathead River; McD Cr, McDonald Creek; Lake McD, Lake McDonald. Shaded area west of Summit is Bear Creek. Small open circles, other dam sites.

the dam. Dam longevity and damage caused by dam formation and subsequent failure were also recorded. The area of avalanche-dammed reservoirs was delineated (based on historical descriptions), plotted on 1:24,000 scale topographic maps, and multiplied by depth of inundation to derive rudimentary volume estimates. Because no empirically-derived formula exists for calculating peak discharge of floods from avalanche-dam failure, estimates were calculated using the methods of Clague and Mathews (1973), and Costa (1988), designed for use with jökulhlaups. These formula relate peak potential discharge (Q_{max}) to reservoir volume (V) based on known historical outburst floods.

Results

Years of Avalanche-Dam Formation

Since Park establishment in 1910, major snow avalanches have been numerous and geographically widespread in 1910, 1929, 1933, 1936, 1939, 1945, 1950, 1952, 1954, 1956, 1957, 1963, 1972, 1975, 1979, 1982, and 1986 (Butler 1986a, 1986b). Discounting those years prior to construction of transportation links, seven of fifteen major avalanche years have also produced hazardous snow avalanche-dams (number of dams in parentheses): 1933 (1), 1939 (2), 1952 (1), 1954 (3), 1956 (3), 1979 (1), and 1982 (1). Avalanche-dams have also been deposited during winters not particularly recognized as major hazard years for snow avalanching; these years include 1935, 1951, 1960, 1970, and 1984, each with one avalanche-dam occurrence recorded in Park and local records.

Location of Snow Avalanche-Dams

Avalanche-dam formation and the associated hazards are concentrated in three locations in Glacier Park (Figure 1): along McDonald Creek, from the head of McDonald Lake to the base of the Garden Wall[2]; along Bear Creek on the southern boundary of the Park[3]; and along the Middle Fork of the Flathead River near the southern tip of the Park[4] (Figure 1). The latter two locations experience avalanches which disrupt traffic along U.S. Highway 2, whereas the former creates conditions damaging to Going-to-the-Sun Road. Two other reported cases from more isolated parts of the Park are also illustrated in Figure 1.[5]

There is no preferred slope direction associated with the formation of avalanche-dams. The avalanches in the Bear Creek area form on south to southeast-facing slopes, those along the Middle Fork of the Flathead form on southwest-facing slopes, and those along McDonald Creek develop on west- to northwest-facing slopes.

Meteorological Conditions Associated with Avalanche-Dam Formation

Precise temperature and precipitation data are not available from avalanche paths in Glacier National Park. However, general statements describing weather conditions and types of avalanche deposits provide some insight into local meteorological conditions during avalanche-dam deposition.

Of the known incidences of avalanche-dam deposition, 59 percent were a result of wet snow avalanches occurring while air temperature was above freezing. This conclusion is not unexpected, given the preponderance of wet snow avalanches in the overall pattern of avalanche types in Glacier Park (Butler 1986a). The remaining 41 percent have little data available for determining type of avalanche and meteorological conditions. The main exception is the deposition of a powder snow dam during a blizzard in 1956, when over two feet (60 cm) of new loose snow was deposited in a period of a few hours.[6] Another dam was deposited in late January 1960 after an unusually heavy snowfall. Temperatures at this time were below freezing.[7]

The patterns of atmospheric flow conducive to major avalanche winters in Glacier National Park have been described by Butler (1986a). Briefly, two alternative synoptic patterns exist which have produced major avalanche cycles in the Park: winters with strong zonal flow, heavy snowfall, and rapidly fluctuating temperatures; and winters with sustained meridional flow and catastrophic avalanching resulting from subsequent invasion and advection of Pacific air. These patterns were shown to be similar to those affecting the Rogers Pass area of British Columbia as described by Fitzharris and Schaerer (1980).

A comparison of years of high frequency avalanching with years in which many avalanche dams were produced reveals that both atmospheric flow-patterns can produce avalanche dams. The winters of 1933 and 1954, for example, were years of strong zonal flow and avalanche-dam deposition; but, the winter of 1979 was strongly meridional in nature and also led to dam production. The key to efficient avalanche-dam development is apparently not so much the overall flow pattern as it is the tendency for warm (above freezing) temperatures and wet snow avalanche occurrence.

Avalanche-Dam Damage and Potential Hazards in Glacier Park

Deposition of avalanche-dams has produced temporary road blockages in and along the boundaries of the Park, as temporary ponds or redirected streams have covered the highways. These blockages produce unaccounted but distinct financial losses for businesses located along Highway 2.

An avalanche-dam deposited in April 1952 blocked McDonald Creek and completely redirected the stream onto the surface of GS Road. The highway was completely soaked, and the springtime snow removal had to be delayed until the road dried out and could bear the weight of heavy snow-clearing equipment.[8] Past blockages of Bear Creek along the southern border of the Park have also temporarily caused submergence of Highway 2.[9] Future occurrences of avalanche-dams along these creeks will undoubtedly lead to similar situations.

Estimated peak discharges (Q_{max}) of past outburst floods vary by location. Estimated Q_{max} values along Bear Creek range from 39 cubic meters per second (cms) utilizing Clague and Mathews' (1973) equation, $Q_{max} = 0.0075 V_{max}^{0.67}$, to about 59 cms using the Costa and Schuster (1988) equation ($Q_{max} = 113 V^{0.64}$, with V in 10^6 m^3 format). Application of the same formulae produces ranges of 56 cms (Clague and Mathews 1973) to about 105 cms (Costa and Schuster 1988) for both McDonald Creek and the Middle Fork of the Flathead River. The Bear Creek value exceeds all historical spring flood discharges except for the catastrophic June 1964 flood (more than 300 cms; Boner and Stermitz 1967). Prior to 1964, the maximum spring discharge flood along Bear Creek was less than 25 cms, a value exceeded by estimated avalanche flood outbursts. Calculated avalanche outburst discharges do not approach the historical maximum of greater than 2500 cms (June 1964; Boner and Stermitz 1967) along the Middle Fork and in excess of 700 cms along McDonald Creek above Lake McDonald. Nevertheless, the avalanche discharge values for these latter two streams may occur approximately once every 3-5 years, whereas the extreme maximum spring flood values appear but infrequently in the historical record. It is not out of the question for more than one avalanche-outburst flood to occur at one location in one winter, if several temporary avalanche-dams develop in the same location and subsequently fail.

Several past avalanches have delivered large quantities of downed timber to the damming deposit.[10] This timber can act to anchor and stabilize the snow dam, prolonging its longevity and therefore increasing the size of the temporary reservoir upstream. Upon the inevitable failure of the dam, a greater flood is unleashed which also contains large pieces of timber that act as battering rams along stream banks and at bridge abutments. The past blockages of the Middle Fork of the Flathead River have included large quantities of timber, suggesting the future possibility of a dam efficient enough to produce an outburst flood of sufficient size to damage the highway bridge where US2 leaves Glacier Park and enters the small community of Essex (Figure 1). Destruction of a highway bridge by direct avalanche impact in 1979 caused a month-long closure of US2 and necessitated a 300 km detour; similar impacts would be felt if the bridge spanning the Middle Fork is damaged or destroyed by an avalanche-dam outburst flood.

Conclusions and Recommendations

Avalanches made of wet loose snow are most likely to produce snow avalanche-dams in Glacier National Park. No preferred slope orientation exists for the occurrence of avalanches which produce dams. Avalanche-dams have developed along McDonald Creek, Bear Creek, and the Middle Fork of the Flathead River, under synoptic conditions of both zonal and meridional flow. Avalanche-dams have dammed reservoirs which temporarily inundate transportation lines in and adjacent to the Park. Calculated volume estimates and peak discharges from avalanche-dam reservoir formation and failure provide mute testament to the destructive capabilities of these natural hazards. Potential exists for outburst floods from avalanche-dams which could destroy highway transportation along the southern edge of the Park. Future avalanche-dams and resultant hazards in the area are likely. As has been shown elsewhere (Butler 1987) local residents who frequently drive on US2 are largely unaware of the extent of the snow avalanche hazard in the area. It is likely that future avalanche-dam outburst floods could produce serious damages and possible loss of life.

The National Park Service and Montana Department of Highways should be made aware of these potential hazards, and road-crew employees should be cognizant of conditions conducive to dam formation and failure. Because of the nature of its mission, the National Park Service is unlikely to engage in any widespread engineering practices within the Park along McDonald Creek to mitigate the hazard. Rather, monitoring and temporary road closures will probably be the most cost-effective method of dealing with the hazard during spring snow clearance. Little can be done to prevent avalanche deposits from damming Bear Creek and the Middle Fork, and few options exist for highway rerouting in the confines of the narrow canyons where the streams and highway parallel each other. Along U.S. 2, the Montana Department of Transportation should also anticipate weather conditions conducive to dam development and outburst flooding, and prepare for temporary road closures during time of high risk.

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Notes

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8. *Hungry Horse News,* 11 April 1952, *op cit.*
9. *Hungry Horse News,* 2 March 1956a, b, *op cit.*
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