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Hazardous Wind Events in Glacier National Park, Montana

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Every weekly issue of a local newspaper that provides news coverage of Glacier National Park, Montana, covering a ten-year time span, was read for information concerning damage from hazardous winds. All such incidents were recorded and mapped. The influence of the Continental Divide on the park's climate was seen in the nature of wind events and resultant damage. West of the divide, hazardous wind events primarily were associated with autumn and winter blizzards, producing wet snow and high winds that toppled and snapped trees; and early-summer frontal storms. East of the divide, the primary damage is associated with high winds associated with winter-season chinooks, or from late-autumn and winter blizzards resulting from the passage of cold fronts, both leading to damage to roofs and windows. On average, approximately two hazardous wind events occurred each year. The ten years of data illustrated peaks of activity in October through January, and in June. These peaks are related to the precipitation patterns and weather systems affecting the park. Little can be done to ameliorate the exposure to hazardous wind events in the park, but expanded education efforts could provide better advance knowledge of the hazard. *Key Words: natural hazards, hazardous winds, Glacier National Park.*

The study of natural hazards occupies a central role in environmental geography, interweaving the physical processes of the Earth with human interactions with the natural environment. Introductory textbooks that describe the geophysical nature of natural hazards typically subdivide their subject matter into geological and geomorphological hazards in one section, and atmospheric hazards in another. Within the atmospheric section of such books, wind hazards are described in association with the meteorological phenomena of hurricanes and tornadoes. Only a very few hazards texts deal with high winds disassociated from hurricanes and tornadoes, but which are rather a result of

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severe windstorms associated with frontal passages, chinooks, or squall lines (see Whittow 1979; Smith 1992). Such an emphasis is justifiable in the context of both loss of lives and economic impacts. Nevertheless, local winds can also be hazardous to people and have economic repercussions. Specific research studies examining more local wind phenomena include Miller's (1968) examination of the relationship between Santa Ana winds and crime in southern California (see also Monteverdi 1973); Miller *et al.'s* (1974) study of chinook and related wind phenomena in Boulder, Colorado; Kleyla and Peterson's (1990) examination of a regional-scale windstorm affecting the South Dakota-Nebraska-Iowa borderlands; Hopkins's (1994) study of the December 1992 windstorm affecting Anchorage, Alaska; and the recent discussion of the *föhn* phenomenon in the former Czechoslovakia by Hrádek *et al.* (1997).

This article examines the nature, timing, and distribution of heavy windstorms and associated hazards, using a popular national park in the United States as a case study. Direct windstorm impacts result when strong winds (typically estimated at >50 miles per hour) produce damage to park structures, facilities, and equipment, and could result in direct physical harm to people caught in the windstorm. Indirect impacts are numerous; they include road closures resulting from trees blown onto highway surfaces, the economic cost of removal of blowdowns, and disruptions to outdoor activities typically associated with a national park setting. The article uses a local newspaper as a data source for examining natural hazards in an environment where wind hazards are geographically widespread, but where meteorological data-collecting stations are few in number.

The Study Area

Glacier National Park is a United Nations-designated International Biosphere Reserve comprising approximately one million acres astride the Continental Divide in northwestern Montana (Figure 1). Approximately two million people visit the park each year, primarily in the summer months, although winter usage of the park has accelerated in the past decade (Rockwell 1995). The bulk of these visitors are concentrated within the main transportation corridors. No educational information is provided to visitors about wind hazards as they enter the park—an

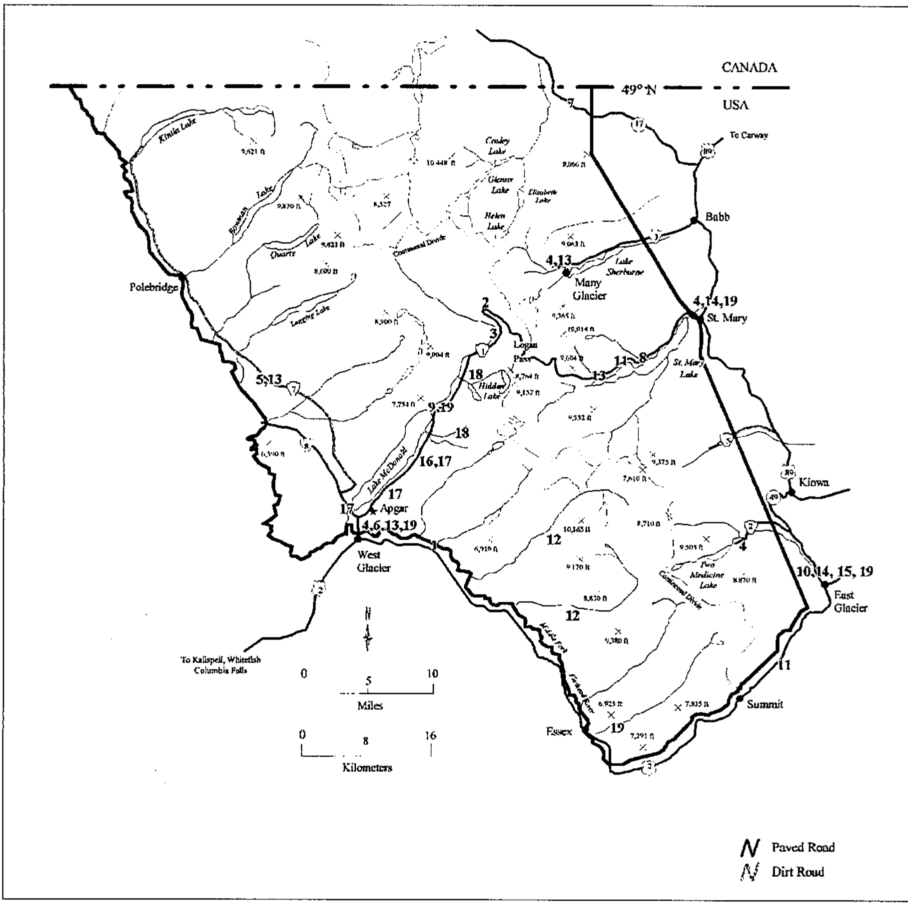

Figure 1. Map of Glacier National Park in northwestern Montana, illustrating the location of all recorded wind-hazard incidences. The number at each site refers to the corresponding entry in Tables 2, 3, and 4. Fine dashed line is the Continental Divide. Heavy dashed lines are roads. Going-to-the-Sun Road connects West Glacier with St. Mary.

unfortunate situation similar to that of the rockfall (Butler 1990) and snow-avalanche (Butler 1987) hazards in Glacier—nor is any information available on the park's web page, which is a data source for more than 100,000 people per year (Glacier National Park 1998). Damages caused by extreme wind events may be described after-the-fact in park press releases, but these releases are not archived for any longer than the current year.

Small communities whose economic basis is primarily tourism ring the boundary of Glacier National Park. The permanent National Park Service staff live in greatest numbers in the park headquarters of West Glacier, as well as in smaller numbers in St. Mary, East Glacier, and Polebridge. Permanent non-Park Service residents also reside in these small towns. The collective permanent population of these communities is several hundred, but the number swells to about four to five times this number during the height of the tourist season.

The Continental Divide exerts a tremendous influence on the climate of Glacier National Park, subdividing the park into a moist, modified-Pacific maritime climatic zone west of the divide, and a harsher continental-type zone east of the divide. The vegetation west and east of the divide reflects this dichotomy. Tall forests of western hemlock, western red cedar, Douglas fir, and western white pine dominate the landscape west of the divide, whereas more stunted and more sparsely distributed Engelmann spruce, subalpine fir, and aspen typify the drier eastern half of the park (Butler 1979).

Glacier National Park was specifically chosen for this study because personal experiences of the senior author vouch for the windy character of the park, and because Glacier National Park is the subject of a long-term, on-going study of natural hazards. Anecdotal and limited historical accounts (*Hungry Horse News*, 13 January 1983, 12 October 1988, 2 November 1989, 21 December 1989, and 21 October 1993; see also Fraley 1994) describe past extreme wind events and their consequences, and winter winds laden with ice crystals depress the local upper treeline well below the elevation limit normal for the latitude of Glacier National Park (Walsh *et al.*, 1992; Rockwell, 1995). The nature and alignment of the terrain, with major glacial valleys aligned parallel to the southwest-prevailing winds (Finklin, 1986), combine with the funneling effect of mountain passes (Rockwell, 1995) to maximize wind speeds.

Weather stations are scattered only around the perimeter of Glacier National Park; no permanent stations exist within its boundaries (see Figure 1). Three year-round climatological substations of the National Weather Service with varying lengths of record exist. The stations include West Glacier (period of record continuous since 1926), Polebridge (complete data from 1947 to the present), and Summit (observations from 1935 to 1979) (Finklin 1986). Sporadic and incomplete weather data, primarily temperature and/or precipitation only, have also been collected at St. Mary, East Glacier, and Essex on the park perimeter, and at Babb, east of the park. Wind data for Glacier National Park are particularly incomplete, but Finklin (1986: 11) states that the exposed mountainous terrain east of the Continental Divide has a "pronounced windspeed maximum in winter and a minimum in summer (July-August)," whereas the "western valleys tend to have a windspeed minimum in winter . . . and a maximum in spring." Chinook winds up to 100 miles per hour have been reported along the eastern edge of the park (Finklin 1986).

Methods

We determined through conversations with several key park personnel (including scientists both in the National Park Service and in the Biological Research Division of the U.S. Geological Survey stationed in the park, and the park archivist) that data on extreme wind events are not officially tabulated in Glacier National Park. Furthermore, National Oceanic and Atmospheric Administration/ National Weather Service publications, such as *Storm Data*, the *Daily Weather Maps Weekly Series*, and *Weekly Weather and Crop Bulletin,* provide only synoptic-scale views of atmospheric conditions during times of local extreme wind events in the park. It was therefore necessary to utilize the resources of the weekly newspaper that chronicles events in Galcier National Park, the *Hungry Horse News* of Columbia Falls, Montana, to provide a local perspective on hazardous wind events that could be examined at the synoptic scale in National Weather Service publications.

Every issue of the *Hungry Horse News* from 1988 through 1997 was read cover-to-cover, and all news items concerning damaging winds (high wind events that caused damage and/or injuries) in Glacier National Park were noted. Visitation to the park began to routinely exceed two million visitors per year during the late 1980s, so this time frame encompasses the period of maximum public exposure to the potential for hazardous wind events. The nature and, if given, economic extent of wind damage was tabulated. The geographic location of the damage was plotted on a park map. The types of weather conditions generating the wind damage, if specified, were recorded. The date of occurrence of each damaging event was recorded and subsequently tabulated by month. The same dates were also examined in the *Weekly Weather and Crop Bulletin* in order to classify the hazardous wind events into proper meteorological terminology.

Results

Number of Events. We recorded a minimum of nineteen hazardous wind events, and possibly as many as twenty-two. The ambiguity in number results from two factors: one report did not specify the month, noting only that a damaging event had occurred during "winter"; and some dates experienced high winds and related damage on both sides of the Continental Divide, but insufficient data precluded a determination of whether such occurrences were park-wide phenomena or, rather, two or more coincidental isolated events at several locations. We believe the former is more likely, given the synoptic settings described in the *Weekly Weather and Crop Bulletin* reports, but we chose to be conservative in our classification in order not to overrepresent the total number of hazardous wind events.

Monthly Distribution of Events. The hazardous wind events were not evenly distributed by month of occurrence (Table 1). A bimodal distribution is evident, with the greatest number occurring in late autumn and early winter, and a secondary peak in June. These two periods coincide with the periods of maximum precipitation in Glacier National Park, typically delivered as frontal precipitation in the late autumn and winter, and as convectional storms coinciding with stagnating Pacific fronts in June (Finklin 1986). Late autumn and winter wind events oc-

Table 1. Month of occurrence and location of recorded damaging wind events.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
West of Continental Divide	1	1	-	-	-	4	1	-	-	3	1	-
East of Continental Divide	2	-	-	-	-	2	-	-	1	2	2	1

N =18 wind events of known date of occurrence during the study period (1988-1997). Three events affected both west and east sides of the park, for a total of 21 in the table. One additional event occurred on an unspecified "winter" date.

curred on both sides of the Continental Divide, as did the June convectional storms.

July and August are the driest months throughout Glacier National Park, and Finklin (1986) noted the dearth of windy conditions on the east side of the Continental Divide during those months. Our results echo that conclusion on a park-wide basis. The absence of damaging winds between March and May reflects the transitional nature of the weather at that time of year—*i.e.,* Pacific fronts are typically weaker than during the winter months, and insufficient warming of the ground surface has occurred to spawn local convectional cells with their attendant high winds.

At first glance, our results for the winter months are in apparent contradiction to those of Finklin with reference to the area west of the Continental Divide. Finklin noted that wind speeds are at a minimum in the western valleys in winter, whereas our results illustrate a major peak in winter months. This apparent contradiction is easily explained: Finklin was reporting average wind speeds from West Glacier and Polebridge, not isolated hazardous wind events.

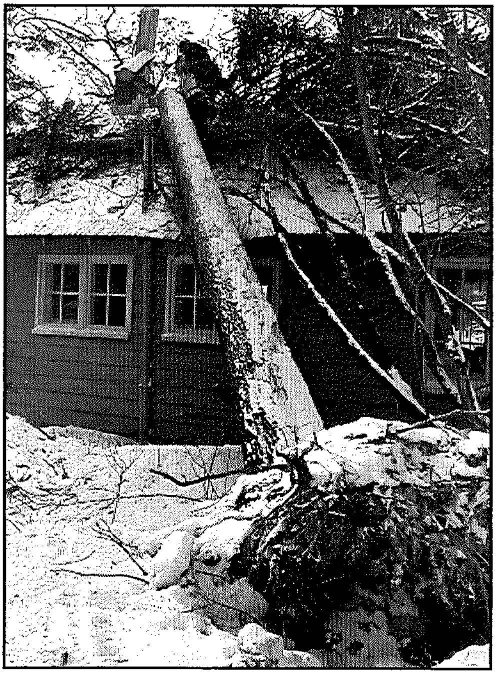

Figure 2. Storm of 31 January 1989: Blizzard conditions of high winds and heavy snows resulted in snapped and uprooted trees, wreaking havoc on the infrastructure of the park's headquarters. Photo by Brian Kennedy, courtesy of *Hungry Horse News.*

Type and Geographic Extent of Wind Damage. The geographical distribution of wind damage illustrates that hazardous winds are a park-wide phenomenon (see Figure 1). However, the geographical coverage of the wind events varies, as does the typical type of damage found west and east of the Continental Divide. West of the divide, hazardous wind events are primarily associated with autumn snowstorms and winter blizzards (Table 2). Large quantities of wet snow in combination with winds in excess of fifty miles per hour produce the typical westside event: widespread toppling and snapping of the large modified-Pacific forest trees,

Table 2. Wind events and resultant damage: West of the Continental Divide.

Date	Description[1]	Site #/Location[2]	Damage
15 Jun 97	Unspecified; "the storm was blowing pretty good"	#1: Middle Fork of Flathead River, near Harrison Creek	Tree fell onto rafting party, injuring three
Unknown; winter 95-96	"Strong winter winds"	#2: Granite Park Chalet	Shingles ripped off roof ridge; damage estimated at $1,000
2 Oct 94	"Autumn snowstorm" (cold front)	#3: Going-to-the-Sun Road, below westside tunnel	3-foot diameter tree blown across the road
6 Jun 94	Winds accompanying areawide storm	#5: Inside North Fork Road	Several trees toppled onto road
21 Nov 93	"Winter blizzard" (slow-moving winter storm)	#6: Park headquarters	Trees toppled
12 Jun 92	Unspecified "windstorm" (major storm, cold front)	#9: Head of Lake McDonald	Tree knocked across power lines, causing power outage
Oct 91; day unspecified	"Heavy wind storm"	#12: Lower Coal Creek and South Boundary Trail; Nyack Trail	More than 600 downed trees on Coal Creek trail; more than 2,600 trees on Nyack trail
10 Feb 90	"Chinook wind with gusts up to 50 mph"	#16: Going-to-the-Sun Road, along Lake McDonald	Road closed by fallen trees
31 Jul 89	"Evening storm with strong winds" (convectional thunderstorms)	#17: Apgar, Lake McDonald, Sprague Creek Campground	Trees, some snapped off 50 feet above ground, blown across road and in campgrounds; six vehicles damaged; one woman slightly injured by falling branch
31 Jan 89	"Severe windstorm"	#18: Sperry Trail; Trail of the Cedars	More than 100 large trees blown across Sperry Trail; boardwalk on Trail of the Cedars smashed by fallen tree

Sources: Allen 1997; *Hungry Horse News* 20 June 1996, 6 October 1994, 6 June 1994, 25 November 1993, 18 June 1992, 2 July 1992, 27 August 1992, 15 February 1990, 2 August 1989, 1 February 1989.

[1]Descriptions in quotation marks are from *Hungry Horse News.* Those in parentheses are from the *Weekly Weather and Crop Bulletin.* In several cases, the latter source had no specific information available.

[2]"Site #" corresponds to the location of the wind event shown on the map in Figure 1.

with attendant damage to structures, facilities, power and electrical lines, and vehicles (Figure 2). Road closures and trail blockages also result from these windstorms. Power and telephone outages are common, and human lives are in jeopardy as trees topple onto houses and vehicles. The weather systems that generate the typical westside wind damage are widespread and can cover an area from the North Fork region to the southern part of the park.

Damaging winds associated with snowstorms are not restricted to the west side of the park, as was witnessed along the Chief Mountain Highway during an October snowstorm (Anonymous 1992d), but such eastside events are distinctly fewer in number (Table 3). They also do not wreak the havoc of similar storms

Table 3. Wind events and resultant damage: East of the Continental Divide.

Date	Description[1]	Site #/Location[2]	Damage
16 Oct 92	High winds in snow storm (cold front)	#7: Chief Mountain Road, northeast corner of park	"Numerous" trees toppled onto road, requiring removal and closing road from park boundary to Canadian border
4-5 Sep 92	"50 mph windstorm" (cold front)	#8: Near Rising Sun boat dock	Winds and rough water caused a tugboat and barge to sink, releasing ~50 gallons of diesel fuel into St. Mary Lake
17 Jan 92	"100 mph wind"	#10: Midvale Creek bridge, East Glacier	Eleven boxcars blown off railroad tracks, six cars going over Midvale Creek bridge
11 Nov 91	"Heavy wind storm"; winds up to 80 mph (strong cold front)	#11: Going-to-the-Sun Road; east of Marias Pass	Television commercial-filming crew disrupted
7-8 Dec 90	Winds >100 mph (chinook)	#14: East Glacier; St. Mary	Shutters blown off buildings; trees blown down
23 Nov 90	"Winds of 102 mph in association with 2 inches of cold rain" (cold front)	#15: East Glacier	Unspecified

Sources: Anonymous 1992d; Kennedy 1992 a, 1992b, 1992c; *Hungry Horse News* 14 November 1991, 13 December 1990, 29 November 1990.

[1]Descriptions in quotation marks are from *Hungry Horse News*. Those in parentheses are from the *Weekly Weather and Crop Bulletin*. In several cases, the latter source had no specific information available.

[2]"Site #" corresponds to the location of the wind event shown on the map in Figure 1.

Table 4. Wind events and resultant damage affecting both sides of the park

Date	Description[1]	Site #/Location[2]	Damage
6 Jun 94	"Funnel clouds" (quasi-stationary front)	#4: approximately 60 km southeast of park	Knocked out telephone service at park headquarters in West Glacier; telephone and power outage at Two Medicine, St. Mary, and Many Glacier
16 Oct 91[3]	"High winds, a gust of wind >100 mph at Many Glacier" (winds in advance of a sharp cold front)	#13: West Glacier; Inside North Fork Road; Going-to-the-Sun Road; Many Glacier	Power knocked out in West Glacier; trees across the roads; portion of roof torn off historic hotel and smashed into another part of roof; four 30-by-54-inch windows blown out; windows in vehicles shattered; roof blown off shed; windows blown out in gas station; portion of roof lost on women's dorm

Sources: *Hungry Horse News,* 9 June 1994, 17 October 1991; Kennedy 1991.
[1]Descriptions in quotation marks are from *Hungry Horse News.* Those in parentheses are from the *Weekly Weather and Crop Bulletin.* In several cases, the latter source had no specific information available.
[2]"Site #" corresponds to the location of the wind event shown on the map in Figure 1.
[3]Possibly the same storm as "Oct 91; day unspecified" in Table 2.

west of the Continental Divide, because of the smaller, stunted, and less dense forests that typify the eastern slopes of the park, and because of the drier snow characterizing the eastern part of the park (Finklin 1986).

In addition to autumn snowstorms with high winds, the area east of the Continental Divide also experiences winter winds associated with blizzards, warm chinook winds in excess of 100 miles per hour, and more localized winds resulting from convectional storms in June. The winter blizzards and the chinooks both produce the type of damage typical for an eastside event: roofs are stripped and in some cases completely destroyed, shutters are blown off, car and home windows are blown out, mobile homes are rocked and shifted, and, in extreme cases, rail cars along the southeastern boundary of the park near and in East Glacier are blown off the track. Wind speeds east of the divide are, as previously noted, accelerated because of the funneling effect of passes on the Continental Divide and the orientation of glacial valleys.

Two hazardous wind events east of the Continental Divide are noteworthy for their unusual nature and resulting damage (Table 4). The first occurred in June 1994 when an area-wide storm uprooted and knocked over hundreds of trees west of the Continental Divide along the Inside North Fork Road. The same storm traveled across the divide and gained additional strength from the warm ground surface east of the mountains. Funnel clouds approximately 60 km southeast of East Glacier, and the high winds in that area, knocked out the power and telephone lines that serve Glacier National Park. Power was knocked out across the east side of the park at Two Medicine, St. Mary, and Many Glacier, and telephones were also rendered inoperable there as well as across the divide at park headquarters in West Glacier.

The second unusual event occurred during the night of 4 September 1992. Winds in excess of fifty miles per hour produced high waves on St. Mary Lake, which swamped a tugboat and barge that were used in delivering materials to a

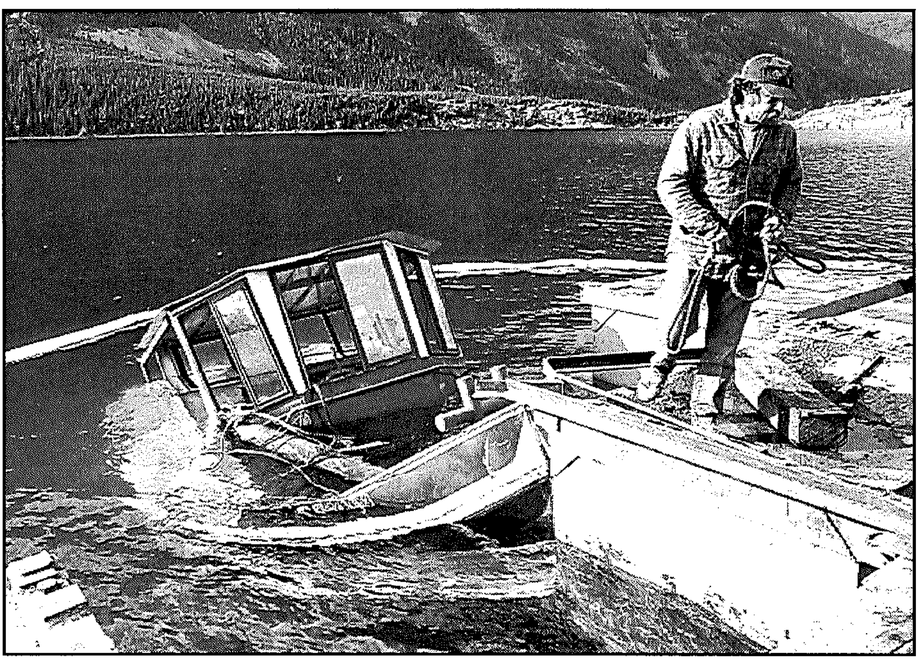

Figure 3. Winds estimated in excess of 50 miles per hour caused a tugboat to sink on St. Mary Lake, September 1992, releasing more than 50 gallons of diesel fuel into the pristine waters of the lake. Photo by Brian Kennedy, courtesy of the *Hungry Horse News*.

highway construction site along the edge of the lake (Figure 3). The sinking of the tugboat resulted in the release of approximately fifty gallons of diesel fuel into the pristine waters of St. Mary Lake, producing a visible slick on the lake surface (Kennedy 1992b, 1992c).

Discussion and Conclusions

We recognize that the use of newspaper accounts for reconstructing hazardous events has its limitations. Wind events that occur away from lines of transportation and communication, or which do not directly affect the peripheral communities surrounding Glacier National Park, may go unrecorded. Our data may thus provide only a minimum number of wind events. A comparison of data not included in our study for the current year (1998) does reveal, however, that all damaging wind events described in park press releases were also described in the *Hungry Horse News*, and that the newspaper provides *more* descriptions of hazardous snow-avalanche events in the park than do the park press releases. We are confident, therefore, that the temporal and geographical patterns revealed in the newspaper provide an accurate portrayal of the frequency and distribution of extreme winds and associated damage over the ten-year period of study.

Little amelioration of wind hazards in Glacier National Park is possible. Radio reception is notoriously weak and sporadic in the park, such that NOAA severe-weather alerts cannot be received with any level of reliability in advance of extreme events. Hazard reduction by changing the environment is also out of the question. Falling trees along roads and adjacent to structures, occurring both in association with winter blizzards and early-summer convectional storms, produce much of the damage on the west side of the park, but removal of such trees from the vicinity of roads and structures is not feasible—environmental protection groups have litigated successfully against any such removal in the park (Berg 1998). Damage from hazardous wind events on the park's east side would be avoidable only if structures are built to exceed hurricane-strength winds associated with blizzards or chinooks, but the costs of such new construction or retrofitting of old structures would be prohibitive to the local economy.

Glacier is not the only national park in the western United States that is susceptible to wind damage. Press releases from other western national parks (*e.g.*, Zion National Park 1998) illustrate that hazardous wind events affect several such parks. Press releases are, unfortunately, a reaction to an event that has already occurred. A survey of the information-rich home pages of nearly every western and southwestern U.S. national park (including Arches, Big Bend, Bryce Canyon, Canyonlands, Capitol Reef, Death Valley, Grand Canyon, Grand Teton, Great Basin, Guadalupe Mountains, Mount Ranier, North Cascades, Olympic, Sequoia and Kings Canyon, Yellowstone, Yosemite, and Zion) revealed that only Guadalupe Mountains National Park (1998) actually mentions wind hazards as a factor that visitors may wish to consider when planning a visit. Given the unrealistic opportunities for hazard amelioration in Glacier National Park and elsewhere, education seems the only viable option for residents and visitors alike.

Wind hazards in Glacier National Park are very real. It is our hope that data such as provided in this article will result in a clearer understanding of the hazardous nature of the Glacier National Park landscape. We also hope to point toward the need for providing additional information on wind hazards in the park, as well as in other western national parks where hazardous wind events occur.

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