CHAPTER 1-- INTRODUCTION

1.1 Purpose and Scope of Study

Crested Butte Mountain Resort (CBMR) has proposed developing a new area of lift-served skiing on Snodgrass Mountain, which lies northwest of the existing ski area on Mount Crested Butte. Like the existing Crested Butte ski area on Mt. Crested Butte, the "Snodgrass ski area" (informal termed used herein, not an official name) is underlain by Mancos Shale which has evidence of large (up to 20 acres) prehistoric landslides and small (less than 1 acre) historic slope instability. Geological and hydrological studies in the Snodgrass Mountain expansion area are necessary for three main objectives:

(1) to define the existing "hydrologic and geologic baseline" conditions on Snodgrass Mountain, particularly those controlling landslides
(2) to permit us to assess any changes in baseline hydrologic and geologic conditions once the ski area is in operation
(3) to form a basis for designing a "slope-stability-neutral" development plan for the proposed ski area development. Under such a plan, possible negative effects of development on slope stability are offset by mitigation actions.

This report mainly summarizes work performed by GEO-HAZ Consulting, Inc. (Crestone, CO) and its subcontractors (Table 1-1) between Fall of 2006 and Fall of 2007. However, earlier published and unpublished studies in the vicinity were incorporated where relevant. The ultimate goal of this study is to determine if ski area development would likely destabilize existing landslides on Snodgrass Mountain, in a manner that would pose a risk to the public, Forest resources, or ski area infrastructure.

Table 1-1. GEO-HAZ Subcontractors and Tasks.
L.A. Smith Drilling, Loma, CO: Borehole Drilling; Piezometer and Inclinometer Installation
HydroGeo Inc., Crested Butte, CO: Borehole Logging; Piezometer Design and Instrumentation; Flume Instrumentation; Record piezometer water levels and stream discharge at flumes; write Groundwater Chapter (Chapter 6).
Resource Engineering Inc., Glenwood Springs, CO: define drainage sub-basins on Snodgrass; perform analysis of surface water data; make runoff predictions; write Surface Water Chapter (Chapter 5).
Schmuser Gordon Meyer Inc., Crested Butte, CO: all surveying on mountain
Jim O'Donnell, Geophysical Consultant, Boulder City, NV; geophysical surveys along main lift corridor; write part of Chapter 3.
Zonge Geosciences, Denver, CO: geophysical surveys in remainder of landslide area; write part of Chapter 3.
Professional Services Industries, Thornton, CO: material testing, computer slope stability analyses; write part of Chapter 9.

This report incorporates some text sections from a previous Progress Report submitted in March, 2007, prior to the 2007 field season and major data collection on Snodgrass Mountain. The complete schedule of past field activities is described more fully in Section 1.4 and in Appendix 1.

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1.1.1 Location and Physiography

Snodgrass Mountain is located NW of Mt. Crested Butte and SE of Gothic Mountain, and lies about 3 miles NE of the town of Crested Butte, and 1 mile north of the town of Mt. Crested Butte. Snodgrass Mountain is a relatively low mountain that reaches only a summit elevation of 11,145 ft, so even the summit is forested. The mountain is elongated in the NW-SE direction, a shape controlled by the laccolithic intrusion that underlies the mountain; this is the same structure responsible for the laccoliths at Mt. Crested Butte and Gothic Mountain.

The NW, NE, and SW sides of Snodgrass are steep, planar, heavily forested slopes developed on the laccolith, and show little to no signs of landsliding. In contrast, the SE side is a lower-angle, complex, hummocky slope that descends toward the broad saddle that separates Snodgrass from Mt. Crested Butte (Fig. 1-1). About half of this slope was mapped by USGS (Gaskill et al, 1991) as being underlain by landslide deposits, a slightly higher percentage than mapped on the basal slopes of Mt. Crested Butte. Most of this report concerns this landslide complex, because it contains >90% of the landslides in the project area.

1.2 Overview of Unstable Slopes in Colorado Ski Areas

The mountain valleys of Colorado were heavily eroded by Pleistocene valley glaciers which retreated for the last time about 15,000 years ago (REF). Glacier retreat left the valleys with the classic U-shape cross-section, with very steep valley sidewalls looming above wide, flat valley floors. When the veterans of the 10th Mountain Division returned from Europe after World War II, quite a few moved to Colorado and began looking for possible sites to develop ski areas. They soon discovered that the steep, planar glacial valley sideslopes of central and western Colorado were everywhere too steep for beginner/intermediate skiing, except in unique areas such as the north face of Aspen Mountain, the north face of Keystone Mountain, Vail Mountain, the north face of Mt. Crested Butte, and others. In those areas, the valley sideslope had been “knocked down” to a lower angle, and the terrain was less steep, less thickly forested, and rolling (hummocky). These areas became the famous ski areas of central and western Colorado.

Although the veterans probably did not realize it at the time, most of the sites they chose as “skiiable” were areas where the post-glacial valley wall had failed due to landsliding. Thus, much of the beginner and intermediate terrain in Colorado ski areas lies on postglacial landslide deposits (McCalpin, 2002). Landslide terrain, with its unique hummocky topography of internal scarps and flats, makes for interesting skiing. Without the existence of these post-glacial landslide complexes, most of Colorado’s mountain slopes would only be developable as ski trails on very steep, planar, avalanche-prone slopes suitable only for experts.

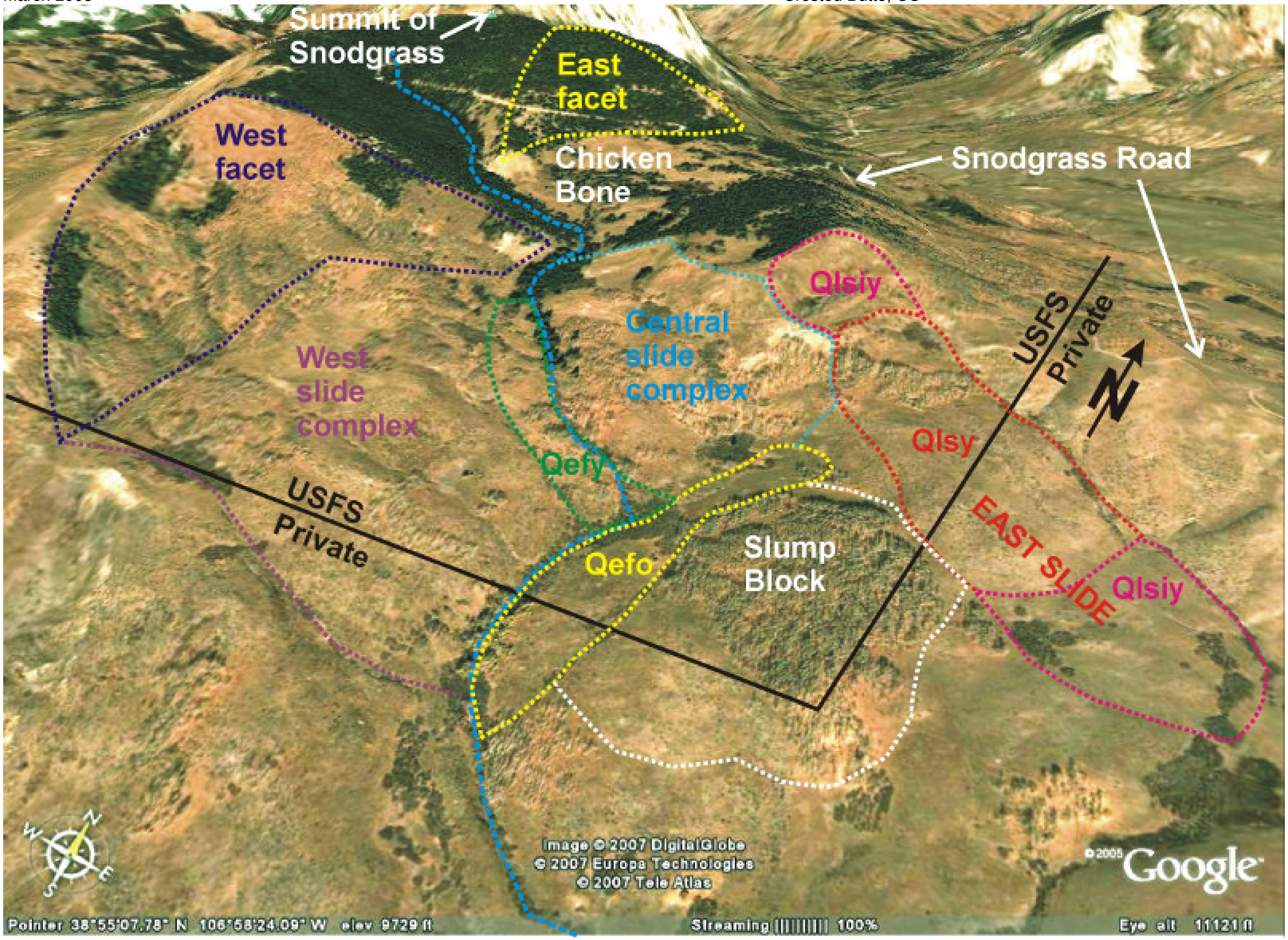

Fig. 1-1. Google Earth image of the southeastern slope of Snodgrass Mountain. Major physiographic features mentioned throughout the text are labeled. Central slide complex is the same as Middle slide complex. Qefy is the Upper Earthflow, Qefo is the Lower Earthflow. This study was mainly limited to the area of USFS land within the black lines, except downslope of the Slump Block and East Slide.

Given the existence of post-glacial landslides at many Colorado ski areas, and the potentially destabilizing effects of trail clearing and snowmaking, one would expect that in the past 50 years these landside complexes might have become reactivated. Generally this has not happened. To the author's knowledge, over the past 50 years no large, thick (>30-50 ft) post-glacial landslide has been catastrophically reactivated in any Colorado ski area. Smaller, thinner, colluvial-scale reactivations have occurred at some ski areas, as well as a creep-reactivation of an earthflow at the Buttermilk ski area in Aspen (Chen-Northern, 1981, 1985, 1991). But wholesale, rapid-movement reactivation has not occurred, even in abnormally wet years such as 1983-1984.

The reason for no large-scale rapid reactivations is unknown, because no definitive slope stability studies have been performed in any Colorado ski area. Possible reasons may include:

(1) Most large, thick landslides occurred immediately after deglaciation, when the oversteepened valley sideslope became de-buttressed by retreating ice. The landslide deposits now lie at a much lower angle than when they failed, and consequently have a higher factor of safety.

(2) The destabilizing effects of ski area development are less than anticipated by the "conventional wisdom", most of which is derived from the published literature on the effects of clear-cutting on steep forested slopes (e.g., Sidle and Ochiai, 2006; Swanson and Dryness, 1975; Swanston and Swanson, 1976). In ski areas, clearing only occurs in narrow strips, rather than large equidimensional areas like clear-cuts. Thus, the cumulative effects fall below the threshold necessary to reactivate the entire prehistoric landslide.

(3) The rapid reactivations that HAVE occurred (generally shallow debris slides/ debris flows) affect only a small, thin part of a thicker preexisting landslide. Typically these failures have occurred where surface runoff has been concentrated by ski areas ditches and diverted onto steep slopes that have no established drainage channels.

(4) In parts of ski areas with no infrastructure, there may be historic creep movement of landslides which has not been recognized, due to a lack of artificial datums. Such movement would be less than a few inches per year, and would not create visible cracks, scarps or disturbed earth. This may be especially true where landslides are composed of plastic shales such as the Mancos Shale (e.g., Buttermilk, Snowmass, Crested Butte) or Belden Shale (Aspen Mountain).

1.3 Relevance of This Study to USFS Decision Making System

1.3.1 April 28, 2006 USFS-CBMR Meeting on Decision System

On April 28, 2006 personnel from CBMR, GEO-HAZ, and the USFS met in Gunnison, CO to discuss how to assess geologic constraints to development on the proposed Snodgrass Mountain ski area. Because the USFS had no preexisting protocol for making such decisions, GEO-HAZ proposed a set of Decision Standards that are outlined below. These Decision Standards provide a pathway in which to evaluate the acceptable level of risk created by landslide processes in a ski area.

BACKGOUND: As explained above, most Colorado ski areas have experienced some type of slope movements since they began operation. These movements range from creep, to slow earthflow movement (e.g., the slowly-stretching Tiehack lift at Buttermilk; Chen-Northern, 1985), to moderate-velocity movements (West Lift landslide of 2000 at Powderhorn; GEO-HAZ, 2000), to very rapid (debris flow of 1996 in Keno Gulch at Aspen Mountain; Wright and Rold, 1996). To date, nobody has been killed or injured by a landslide at a Colorado ski area. In fact, there is only one documented case of a landslide-related fatality at a ski area in the entire world. That incident, at the Thredbo Ski Area in Australia, resulted from the failure of artificial fill which slid into a ski lodge at the base of the mountain. This failure was not a natural landslide, and in fact was caused by a plugged ditch diverting water onto a fill prism placed on a steep slope.

In Colorado slow (creeping) landslide movement has shifted lifts out of alignment over a period of years, necessitating repair or replacement (e.g, Chen-Northern, 1981, 1985, 1991). Resource damage has occurred, primarily via erosion of freshly-slid earth and transport of excess sediment to the nearest stream.

THE DILEMMA: Much landslide terrain in Colorado was created by late glacial valley wall erosion (22,000-35,000 years ago) and subsequent collapse of the oversteepened slopes after glacier retreat (15,000-22,000 years ago). Subsequently, some of the larger failed masses have been periodically reactivated throughout the Holocene era (past 10,000 years), probably in response to wet/cold climate cycles (e.g., the Slumgullion earthflow chronology of Madole, 1996). This type of movement can be expected in the future, as occurred during the wet years of 1984 and 1985, when 15 and 2 Western Slope Counties, respectively, suffered enough landslide and flood damage to be declared disaster areas. (http://www.dola.state.co.us/oem/Mitigation/plan/Hazards_LtoS.pdf.). Thus, the dilemma is how to develop and operate ski areas on mountains that owe their “skiiable” topography to landsliding, without endangering the safety of the public, or causing damage to Forest resources or ski area infrastructure.

PROPOSED DECISION STANDARD 1:

1—The health and safety of the public is paramount. Ski area operations should not expose the public to rapid slope instability processes that have a high probability of directly or indirectly causing death or injury. [An example of direct injury would be a rapidly-moving landslide knocking down a person, burying them with debris, or collapsing a building they were in. An example of indirect injury would be a landslide damaging a lift so fast that it causes a unavoidable and unforeseen derailment, which injures skiers]. This standard is results-based; it does not matter whether the landslide occurs naturally or is caused by human actions.

Decision Support Criteria 1: Landslide areas identified in the permit area should be classified in such way that their potential to cause death or injury as described above can be assessed. Such assessment should include two parts: (1) what is the probability that the future landslide will occur ?, and (2) if the landslide occurs, will its velocity be sufficient to pose a realistic threat of death or injury?

Decision Support Methods 1: the probability of future landslide occurrence can be assessed qualitatively or quantitatively. For qualitative purposes, the probability is assumed to be proportional to the recency of past landslide movement. Recency of landslide movement can be estimated by the morphologic freshness or sharpness of landslide landforms. See morphologic-based landslide age classifications of McCalpin (1984) and Wieczorek (1984). For quantitative estimates of probability. Monte Carlo simulations of the static equilibrium factor of safety equations can be used, as in the USDA-Forest Service LISA computer program.

The velocity (and thus threat to life) of a future landslide can be estimated qualitatively from the type of past landsliding (see Table 1-2).

DECISION STANDARD 2:

1—No mountain activity can result in a net decrease in slope stability in any one landslide or terrain element, beyond the natural, pre-development condition. This does not preclude future slope movements from occurring in the permit area, but such movements will not have been exacerbated by the development actions.

DECISION STANDARD 3:

1—Slow slope movements that do not pose a direct threat to human health and safety, or to failure of man-made facilities, will be compatible with ski trails, as long as they do not cause significant resource damage. Resource damage would include excess sediment production out of a watershed, severe gullying and erosion, runaway progression of landslides upslope, unsightly erosion that destroys or displaces native vegetation, etc.

Table 1-2. Categories of velocities of potential landslides, their probable destructive significance, and their suggested compatibility with various on-mountain activities. Bold landslide types exist in the Snodgrass permit area. These types of landslides generally move slowly enough that people may escape their direct impact. The rapid velocity classes are typically deemed incompatible with most ski area activity.

Landslide Velocity Class[1]	Typical Velocity[1]	Associated Landslide Types[2]	Probable Destructive Significance[1]	COMPATIBLE WITH?		
				Trails	Lifts	Occupied Structures
Extremely Rapid	>5 m/sec	Rock falls, disrupted rock slides, rock avalanches, soil falls, soil avalanches, rapid soil flows	Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths, escape unlikely	**N**	**N**	**N**
Very Rapid	3 m/min . 5 m/sec	Disrupted rock slides, soil avalanches, soil block slides, soil lateral spreads, rapid soil flows	Some lives lost; velocity too great to permit all person to escape	**N**	**N**	**N**
Rapid	1.8 m/hr . 3 m/min	Disrupted rock slides, rock slumps, disrupted soil slides, **soil slumps**, soil block slides	Escape evacuation possible; structures, possessions, and equipment destroyed	**N**	**N**	**N**
Moderate	13 m/ month . 1.8 m/hr	Rock slumps, rock block slides, disrupted soil slides, **soil slumps**, soil block slides, slow earth flows	Some temporary and insensitive structures can be temporarily maintained	Y	**N**	**N**
Slow	1.6 m/yr . 13 m/ month	Rock slumps, rock block slides, **soil slumps**, soil block slides, **slow earth flows**	Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase	Y	Y	Y
Very Slow	16 mm/yr . 1.6 m/yr	**Slow earth flows**	Some permanent structures undamaged by movement	Y	Y	Y
Extremely Slow	<16 mm/yr	**Soil creep**	Continuous movement at an average rate of less than a foot decade **(see Chapter 4, Sec. 4.2)**	Y	Y	Y

1 Cruden and Varnes, 1996
2 Keefer, 1984

1.4 Timeline of Tasks Accomplished [listed by firm]

In late 2006 GEO-HAZ submitted the two initial proposals to collect baseline geological and hydrological data on Snodgrass Mountain. These proposals were submitted as soon as USFS formalized their concerns about slope movement on the lower east side of Snodgrass Mountain (USFS, 2006). The two monitoring proposals (submitted October 11 and 19, 2006) began immediate data collection on surface water and groundwater, in time to include the Spring, 2007 snowmelt season. This season is critical because during the spring snowmelt, surface water flows are largest, shallow groundwater levels are highest, and unstable slopes in Colorado are most active (1997, , 1998).

In October 2006 SGM installed 10 additional landslide monitoring stakes. Due to an early blizzard in the first week of November 2006, only 2 piezometers could be installed before the mountain became inaccessible. Neither of the two planned flumes were installed, but HydroGeo made manual velocity-area measurements of streamflow at the two flume sites during the Spring 2007 snowmelt period.

The bulk of geological, geotechnical, and geophysical data were collected during July 2007, when the remaining 12 piezometers were installed, along with 8 inclinometers and 2 flumes. Data were collected from the inclinometers and monitoring stakes until snow covered the mountain in Fall 2007. However, collection of data from piezometers has continued to the present.

Table 1-3. Timeline of tasks accomplished in this study [by subject and firm].

Year	Month	Surface geology	Subsurface geology	Hydrology- HydroGeo	Hydrology—Resource Engr.	Surveying	Geophysics
2006	Nov	Perform detailed surface geologic mapping before winter snow cover [GEO-HAZ]	Drill 2 boreholes (PZ-15, PZ-16) on CBMR land at base of Snodgrass; continuous split-spoon samples; install piezometers [Smith][1]	Install data loggers in 3 existing RCE piezometers Install data loggers in new piezometers [HydroGeo]		install 10 more slide monitor monuments (rebar) in GHUs 1-6 [SGM]	
	Dec	Assemble GIS database; Write comprehensive plan for future geology studies [GEO-HAZ]		Once a month, Dec. through June: estimates discharge of axial stream from natural X-section Check and down load dataloggers monthly			

				[HydroGeo]			
2007	Jan	Consult with IAD on proposed action [GEO-HAZ]					
	Feb				1-- Finish definition of drainage sub-basins in GIS 2-- Determine appropriate values for input into RUNOFF spreadsheet 3—Run spreadsheet 4—consult with GEO-HAZ and IAD on impacts of development; recommend mitigation		
	March through June				5—Create spreadsheet for total water balance of each sub-basin (all INPUTS and OUTPUTS), including groundwater		
	July	Excavate 2 trenches on East Slide to confirm its margins [GEO-HAZ]	**Drill remaining boreholes (of 16 planned) in GHUs 1-6; continuous split-spoon samples; install piezometers; conduct slug tests in all wells; install 8 inclinometers[2] [Smith]**		6—perform field survey of axial stream channel; assess likely impacts of increased runoff from development		**Run geophysical surveys along main lift line[4] [O'Donnell]**
	Aug-Sept					Survey all monitor stakes, borehole and flume locations; survey fence line across East Slide [SGM]	

	Oct	Assemble Final Report [GEO-HAZ]	Perform slope stability calculations along the 4 stability cross-sections [PSI]	Write Chapter 6 of Final Report [HydroGeo]	Write Chapter 5 of Final Report [Resource]		**Run remaining geophysical surveys in landslide area[4] [Zonge]**
	Nov						
	Dec						
	Jan						
	Feb						
	Mar						