Snodgrass Mountain Geologic Hazards and Assessment of Potential Effects of Ski Area Development on Slope Stability

TECHNICAL REPORT

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by
United States Forest Service
Grand Mesa, Uncompahgre and Gunnison (GMUG)
and San Juan National Forests

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I. INTRODUCTION

The purpose of this *Technical Report* is to classify Snodgrass Mountain according to Geologic Hazard Units (GHU's) having generally similar characteristics, to assess the potential effects of typical ski area activities on slope stability, and to offer possible mitigation measures to minimize these impacts. This report is not intended as an environmental analysis nor does it identify specific landslides. Instead, the intent of this report is to present information that will be useful to the United States Forest Service (USFS) in deciding whether to proceed with an environmental analysis of a proposed ski area on the mountain.

Snodgrass Mountain is located northwest of the existing Crested Butte Ski Area and is being considered for predominately intermediate alpine ski development on Grand Mesa, Uncompahgre and Gunnison (GMUG) National Forest System land. The mountain lies between Gothic Road on the east and Washington Gulch Road on the west and forms a striking pointed backdrop on the skyline north of the town of Mount Crested Butte. The Crested Butte Mountain Resort (CBMR) made an original proposal in 1981 to the USFS. Although it was accepted, it was not acted upon. Then in 1994, another proposal was made by CBMR for expansion of a ski area onto Snodgrass Mountain. Early studies of the geology and geologic hazards of the southern and eastern slopes of the mountain indicated areas of unstable slopes and landslides, which has been noted as a significant issue for the proposed ski area development. In 1996, the application was withdrawn by CBMR. In the Fall of 2004, CBMR revised their proposal, called "Alternative 3" or "Snodgrass Light" to avoid placing liftlines in particularly sensitive slopes and to modify their desired area of development. Due to the current proposal of extending the ski area into areas previously unstudied in detail, the Forest Service requested this work herein to aid decision makers in the pre-NEPA (National Environmental Policy Act) stage of USFS review for the project. Because the USFS regards slope stability issues to be a key component in the review of the proposed project, a thorough study of the potential for slope movement was necessary.

The observations, photographs, interpretations and recommendations associated with the potential geologic hazards within the proposed expansion of the Crested Butte Ski Area and presented in this report are primarily those of Michael Burke, a former Geotechnical Engineer (PE) with the San Juan National Forest. This report is based on the study of previously published documents, project-specific consultant's reports, aerial photographs, geologic and topographic maps, and field observations from the late Fall of 2004 through September 2005. In June 2006, Laurie Hauptmann, a Professional Geologist (PG) with Buckhorn Geotech, Inc. was brought into the project to compile, edit, and generally facilitate the production of this report. Buckhorn Geotech did not field check or verify Burke's field observations or interpretations. Although some geotechnical borings were performed for a previous study (RCE, 1995), no subsurface testing, geotechnical analyses, or modeling of slope stability were included as part of this USFS technical report.

The general geology and site conditions of Snodgrass Mountain have been well documented in previous studies and are summarized herein (Sections II and III). Because the subsurface geology is complex and not all areas on the mountain have been analyzed at the same level of detail, not all landslides on the mountain have been previously mapped. In addition to a brief review of previous work and site conditions, the current report includes a delineation and description of geologic hazards and GHU's, an evaluation of the potential impacts that ski area modifications have on slope stability, and recommended typical mitigation measures. Ski area modifications include activities that would likely occur as a result of developing this land for a ski area, such as grading and slope shaping, clearing, snowmaking, buried utilities, roads, liftlines (towers and terminals) and structures.

A. Site Description

The summit of Snodgrass Mountain (el. 11,145') is located approximately five miles north of the town of Crested Butte and two miles northwest of the town of Mount Crested Butte, at the base of the Crested Butte ski area. It is separated from the existing ski area by a narrow valley (el. ~ 9,400') containing Woods Creek, a small, perennial drainage that flows to the south and bordered to the northeast and southwest by well-developed parallel valleys with larger perennial streams, the East River (el. 9,200') and Washington Gulch (el. 9,520'), respectively. Gothic Mountain is across a small valley two miles to the northwest (el. 12,625'). The topography and vegetative cover is shown on Map 1 (Appendix A), a combined topographic map and orthophoto. The following photograph, taken looking northwest towards Snodgrass Mountain from Gold Link, a residential portion of Mount Crested Butte, shows the general shape and appearance of the southeast side of the mountain and its vegetative cover. The true summit of Snodgrass Mountain is just beyond view near the center of the photograph and Gothic Mountain is the steep, gray peak on the right-hand edge of the photograph.

The main surface drainage (hereafter referred to as the Unnamed Drainage) on the mountain, seen bisecting the middle of the mountain in the photograph above and on Map 1, flows southeast from the summit through a valley between two parallel ridges (South Ridge and North Ridge). The channel appears to seldom carry water on the upper part of the mountain, where the fractured and permeable intrusive igneous rock that caps Snodgrass is found (see *General Geology* Section). The upper half of the mountain, with some variation based on aspect, elevation and disturbance history, is covered with generally thick stands of conifers on moderately steep to steep slopes around some more gently-sloping terrain. The lower half, which is underlain by Mancos Shale, contains stands of aspen, grasses, shrubs, willows and meadows on mostly moderate slopes. There is an extensive network of wetlands on the mid to lower slopes of the southeast and northeast sides of the mountain. These wetlands are mapped in detail by Pioneer Environmental Services (see Exhibit 1 of RCE, 1995).

Some timber harvesting of conifers has occurred on the southeast side of the mountain. There is also some evidence of wildfires. A primitive, native-surfaced road accesses the summit from the Crested Butte base area (see Map 1). The only other man-made infrastructures consist of stock fences and primitive trails.

B. Proposed Ski Area

This report is an analysis of the geologic hazards of USFS land on Snodgrass Mountain as well as an evaluation of the potential effects of ski area activities on slope stability. As such, the boundary of the proposed "Alternative 3" ski area presented by CBMR to the USFS in 2004 was used to focus attention on areas of the mountain that would potentially be developed for intermediate skiing (see "proposed ski area boundary," indicated by a green line on Map 1). Since the trail and liftline locations were preliminary and would be modified by the proponent based on slope stability and other concerns, these features were not included in the mapping used in this report. Because the purpose of this report is to evaluate the current stability of the mountain and to assess the general risks of new or renewed landslide movement due to proposed ski area expansion, analyses of the impacts of <u>specific</u> ski runs, liftlines, road cuts and fills, etc. are beyond the scope of this report. Instead, an effort was made to "divide" the mountain into Geologic Hazard Units (GHU's) that have geologic and behavioral differences. Each GHU was evaluated for the potential impacts to slope stability that would be associated with typical ski area development activities. Typical mitigation measures, including avoidance, are presented.

II. GENERAL GEOLOGY

Snodgrass Mountain is a Tertiary-aged, quartz monzonite porphyry laccolith that had intruded into the marine, Cretaceous Mancos Shale Formation (Gaskill, 1991). A laccolith is an intrusive igneous body of rock that has formed from magma working its way up through the earth and then spreading laterally between layers of bedded, usually sedimentary, rock. It is domed on the top and roughly parallel to the bedding of the sedimentary rock on the bottom, much like the shape of a mushroom. The Snodgrass Laccolith base dips to the southwest towards the Washington Gulch Valley. Subsequent erosion due to water, wind and glaciers has exposed the laccolith and over-steepened its slopes, but the relative hardness of the igneous rock compared to the surrounded Mancos Shale has left a hard-capped mountain. The lower flanks of Snodgrass Mountain contain the weaker Mancos Shale that weathers into mostly clay and silt. According to Irish (1996), the elevation of the contact between the quartz monzonite porphyry and the Mancos Shale is around 10,080 feet at the southeastern end of the mountain.

At some locations in the project area, shale and intrusive igneous rock are interbedded due to movement of magma that forms sills of igneous rock between the weaker sedimentary layers. This layered sequence creates several conditions conducive to landslide development. The thin beds of both igneous intrusive rock and shale dip to the southwest (into the Washington Gulch Valley) and the beds of shale provide weak surfaces upon which the igneous intrusive rock can slide, particularly when the orientation of the bedding and the ground surface are roughly parallel. Additionally, the soil on the upper portion of the mountain is derived from weathering of the quartz monzonite porphyry, which is generally granular and permeable, resulting in rapid infiltration of rain and snowmelt. Based on observations of outcrops and talus slopes, the igneous rock is highly fractured. The extensive and widespread fracturing of the igneous intrusive rock likely creates a high rate of infiltration of rain and snowmelt. Evidence for rapid infiltration of surface water on the upper part of the mountain includes the lack of defined drainage channels and the infrequent flow of water in the Unnamed Drainage in the zone. There are springs with considerable flow even during dry periods but they appear to be located just above beds of shale.

III. PREVIOUS GEOLOGIC AND GEOLOGIC HAZARD WORK

The general geology of Snodgrass Mountain is mapped at 1:24,000 scale on the *Gothic Mountain* and *Oh-Be-Joyful Geologic Quadrangles* (Gaskill et al., 1991 and 1967, respectively). A general discussion of the geology of the region can also be found in the Colorado Geological Survey publication on the geology of Gunnison County (Streufert, 1999). A summary of the mapped geology will be discussed below, but it is important to note that the lower southeast facing slopes of Snodgrass Mountain, including areas proposed by CBMR as ski area terrain, are mapped by the United States Geological Survey (USGS) as "landslide, slump, debris flow and earthflow complexes." The Colorado Geological Survey (CGS) published a report entitled *Geological Hazards in the Crested Butte-Gunnison Area, Gunnison County, Colorado* (Soule, 1976) that included 1:24,000 scale mapping of geologic hazards of the region. According to those maps, all but the flatter areas near the summit of Snodgrass Mountain are mapped as containing landslides, unstable slopes, potentially unstable slopes, debris flows and mud flow areas. Though not detailed enough for evaluation of specific development proposals, the extensive depiction of landslides and potentially unstable slopes supports the need for more intensive studies.

Geologic hazards for the proposed Snodgrass Mountain expansion, with an emphasis on landslides, have been studied several times in the mid 1990's. The first site-specific report was prepared by Resource Consultants & Engineers (RCE) for Crested Butte Mountain Resort in 1995 and addressed the original proposed ski area. Their investigation included field mapping in August 1993 to delineate the surficial geology and geologic hazards, drilling five boreholes along the proposed Gondola route (by Lambert & Associates in October, 1994), aerial photograph interpretation, and review of available geologic maps and geotechnical reports. The RCE report divided the portion of the mountain proposed for ski area development into four zones based on geomorphic landforms and processes. The report included 1:6,000 scale mapping of landslide scarps, shale contact, delineated wetlands, areas of shallow soil creep, and bedrock outcrops. Their main conclusions and recommendations are:

- The southeast-facing portion of the mountain (Zone 3) is the area of highest risk because it is the area of historic landsliding, exhibiting slope creep, shallow debris flows, smaller secondary slides, slow deep-seated movement, and settlement. The planned ski area development will increase the potential for future failures. This area should not be developed without mitigation measures that would increase the overall stability of the slide. All infrastructure should be located outside of the historical landslide mass due to the probable shearing of cables and pipelines.
- Instability problems on the remainder of Snodgrass Mountain are predominately related to shallow soil creep.
- A high proportion of the soils in the proposed development are derived from Mancos Shale which can produce swelling clays that are detrimental to foundations of buildings and lift towers. However, this hazard is commonly mitigated with appropriate foundation design.
- They recommend that the Gondola be placed on the ridgeline to the east of the historic landslide due to the potential for severe damage to the lift and the associated potential for loss of life because of slope movement.
- They recommend both groundwater and slope stability modeling to evaluate an alternative Gondola route. Horizontal drains should be installed in the landslide mass to increase the Factor of Safety to 1.5.
- Subsurface borings along the Gondola route, which is a cross-section through the southeast (Zone 3) landslide, indicate: (1.) presence of shallow groundwater within the landslide mass (11 to 42 feet); (2.) the soils are sandy clays, clayey sands, and stiff clays with low permeability; and (3.) the bedrock beneath the lower slide plane is predominately shale. The depth of landsliding was not noted on the drill logs.
- Much of the south- and southeast-facing slope of Snodgrass Mountain is a historic landslide that has questionable long-term stability. The shale will continue to weather and lose strength, which will decrease the stability of the landslides. Although the likelihood of large mass failures is not regarded as very high, there is a high likelihood of “smaller scale” intermittent sliding within this landslide mass on the order of 1 to 20 acre failures.
- Snowmaking and proposed development features would decrease overall stability of the landslide mass without adequate mitigation.
- There is evidence of fast-moving earthflows in the lower portion of the mountain that could result in damage to structures.

At CBMR’s request, a second site-specific report was prepared by geologist Jim Irish (Irish, 1996). This report focused only on the areas mapped by RCE on the east and southeast portions of Snodgrass Mountain. This was a “geologic fatal flaw” study to “guide initial assessments of the viability of the project.” Irish’s work included review of previous reports and mapping, geologic reconnaissance, interpretation of aerial photographs, and reinterpretation of subsurface borings. The main conclusions and recommendations of the Irish report are:

- The three areas referred to as the East Slope, Lateral Moraine Ridge and Base Hill were determined to be relatively stable.
- The East and West Landslides on the lower southeast portion of the mountain were determined to be post-glacial that do not show evidence of reactivation in historic time. Block-type and mudflow-type failures have occurred in this area. Base Hill buttresses the West Landslide, making it more stable. The East and West Landslides will geologically constrain the project.
- The risk of catastrophic slope failure during the life of the planned ski area is low and should remain low "provided slopes are not impaired by inappropriate construction and operational practices."
- Sensible construction and operation practices include: cuts and fills should be minimized, fills should not block natural ravines, unavoidably large cuts may need to be stabilized with soil anchors and rock bolts, water should not be allowed to pond and infiltrate, runoff should be directed to drainage channels as quickly as possible, cut slopes and redressed slopes on ski runs should be revegetated, and the tree cover should be maintained as much as possible.
- Foundations placed on Mancos-derived soils should be designed to accommodate at least moderate swelling pressures.
- They suggest moving the gondola and Lift N-3 to the east out of the landslide mass and onto lateral moraine and Mancos Shale terrains that are stable. Ski lifts, in general, should be placed outside the limits of the landslide complex.
- Snowmaking would increase the amount of water added to certain slopes, but this is regarded as a small percentage when compared to natural rain and snow amounts over the entire mountain.

Due to differences in interpretation of development impacts and the mapping of some of geologic features between the first two reports prepared for CBMR, the Forest Service requested that Rex Baum with the USGS provide an independent opinion on the landslides. Baum reviewed the RCE and Irish reports, performed his own geologic reconnaissance in August 1996, interpreted aerial photographs, and produced a report (Baum, 1996). Baum divided the southeast landslide complex of Snodgrass Mountain into three main units: the Slump Block, the West Slide, and the East Slide. The West and East Slides are similar to those previously discussed, but Baum interprets the Slump Block as a landslide complex rather than in-place shale bedrock, as asserted by Irish (1996). The main conclusions and recommendations of the Baum report are:

- The East Slide and portions of the Slump Block were calculated to be as much as 60 feet thick. Insufficient data is available to determine the thickness of the West Slide.
- The absolute ages of the three slides are not known, but the observations that the East Slide overlaps the Slump Block and that the West Slide and Slump Block are more deeply eroded and have more rounded features than the East Slide, indicate that the East Slide is the youngest landform of the three.
- Due to analysis of photographs of the mountain that span 30 years (from 1958 to 1988), Baum concludes that the three slide areas have not moved significantly in historic times. However, he qualifies that statement with the comment that slides can be marginally active with very small annual movement without evidence of cracks or other evidence being preserved on the surface.

- A recent slide on the south side of Snodgrass Mountain, outside of the Forest Service boundary, appears to have been active in the past 40 years. The East Slide, West Slide and Slump Blocks all have some slopes as steep as the recent slide.
- Earthflows are highly likely during the life of the project in the lower southeast slope of Snodgrass Mountain during times of high rainfall or rapid snowmelt. Recent (1996) earthflows on similar conditions demonstrate the potential for this hazard.
- Shallow sliding and slumping are likely to occur on all three landslide areas over the life of the development. Hazards can be reduced by appropriate engineering but maintenance could be costly.
- Deep-seated failure and renewed movement of the entire landslide complex (all three components) would threaten all of the proposed facilities in that area. Since the Slump Block buttresses deposits on the West Slide, special care of the Slump Block from erosion and deep cuts into its toe or crest will be very important to maintain the stability of the Slump Block.
- Deep-seated failure and reactivation of the East Slide is more likely than reactivation of the entire landslide complex. Baum suggests avoidance of any development or snowmaking on the East Slide and site-specific studies to evaluate other possible mitigation options.
- Snowmaking is likely to aggravate the hazards of shallow slumping, deep-seated sliding and earthflows.
- Detailed subsurface investigations and engineering (slope stability) analyses are needed to predict whether the slide deposits will remain stable during the life of the proposed facilities. Quantitative data such as shear strength, geometry (topography and thickness), and pore-pressure measurements within the landslide deposits are necessary to assist in determining the stability of the slope.

At an April 28, 2005, meeting of Forest Service and CBMR personnel, Jim McCalpin, a geologist working for the proponent, presented to Forest Service and CBMR personnel a document entitled *Draft Decision Standards: Acceptability of Slope Movements in Ski Permit Areas* (McCalpin, 1985). His methods were considered in the risk assessment of this USFS report. In addition, McCalpin's earlier paper entitled *Preliminary Age Classification of Landslides for Inventory Mapping* (McCalpin, 1984) was used as a standard for using geomorphic characteristics of landslides to evaluate their age and stability. McCalpin (2005) points out that "most beginner and intermediate ski terrain in Colorado lies on postglacial landslide deposits [Vail, Aspen, Keystone, etc.], which is responsible for 'knocking down' the typical steep mountain slopes and making them skiable." He goes on to say that, "without landslides, most of Colorado's mountain slopes would only be developable as ski trails on very steep, planar, avalanche-prone slopes suitable for experts." Due to glacial scouring of mountain valleys, many of the valley walls were left over-steepened when the glaciers retreated. This activity also left behind unconsolidated glacial debris perched on the mountainsides. The melting glaciers, combined with postglacial climatic conditions that were more moist than present conditions, produced saturated soil and rock on steep mountain terrain that was susceptible to slope failure. Many of the large slope failures in the region are attributed to this postglacial moisture, as well as cyclical wet climate cycles throughout the Holocene era (past 10,000 years). Since most of the lower flanks of mountains throughout Colorado are composed of these geologically recent (Quaternary) landslide deposits, the dilemma for developing ski areas, as summarized by McCalpin (2005) is “how to operate ski areas on mountains that owe their topography to landsliding, without endangering the safety of the public, or subjecting Forest resources or ski area infrastructure to unacceptable levels of risk.”

On June 24, 2005, Michael Burke led a field review of his preliminary assessments of landslide processes and potential hazards. In attendance were Jim McCalpin, Terry Hughes (USFS soil scientist), John Almy (USFS hydrologist), and Roark Kiklevich (CBMR). The results of that field meeting are documented in a letter report from Jim McCalpin to CBMR (McCalpin, 2005). McCalpin’s main observations and conclusions of the landslide hazards, as summarized in that letter, are:

- The hazard potential in three of the four specific problem areas defined by Burke were overestimated and could be mitigated considerably by altered placement or standard engineering practices.
- A critical issue to consider is the routing of surface runoff and the destabilizing effects of additional runoff and infiltration from snowmaking.
- He recommends an aggressive surface water control design that makes the cumulative development of Snodgrass Mountain “stability-neutral.” In other words, the destabilizing effects of snowmaking are offset by a more efficient network of surface runoff ditches that removes water from the mountain faster than at present.

A recent report by Cotton, Shires & Associates (CSA, 2006) for the High Country Citizen’s Alliance provides a comprehensive review of the previous geologic and geologic hazard work performed on Snodgrass Mountain. It also includes a comprehensive map of the geology and geologic hazards, to be discussed below, from Gaskill at al. (1991), Soule (1976), RCE (1995), Irish (1996) and Baum (1996). No additional studies of the mountain were performed in preparation of the CSA (2006) report.

IV. GEOLOGIC HAZARDS

The primary purpose of this report is to assess the nature and extent of the landslide/slope movement features on the mountain. However, other geologic hazards exist on Snodgrass Mountain and should be mentioned in this report, as geologic hazards have potential impacts on the feasibility and/or constructability of a ski area on the mountain. Conversely, ski area development can have an impact on geologic hazards. For example, the construction of roads can disrupt the balance of loads on a slope and potentially impact its stability. Therefore, a general discussion of geologic hazards is warranted at this time to identify the hazards present and whether they will be evaluated in this report or under separate investigations.

A. **Landslides/Earthflows/Unstable Slopes –** Landslides are a form of mass wasting where rock, soil and debris move downslope under the influence of gravity. Many slopes in the region are susceptible to slope movement because of a number of reasons such as the dip of weak shale bedrock into the valley, the presence of abundant water that can lubricate and weather (weaken) soil and rock, the over-steepened valley walls from glaciation and previous landslides or erosion, and man’s activities that have cut the toes of slopes and/or weighted the crest of steep slopes. An “unstable slope” according to Soule (1976) is a “slope with landslide-earthflow physiography, but where modern slope movement is not apparent or is uncertain. Such areas have undergone slope movement in the recent geologic past (late Pleistocene-Holocene). Owing to climate changes and other factors, some of these areas have become stabilized in the natural state, whereas other places are metastable or possibly even slowly failing (moving) at the present time." In contrast, Soule identifies a "landslide-earthflow area" as an "area with demonstrably active natural movement of landslide and/or earthflows. Evidence for modern slope movement(s) includes distinctive physiography and disrupted vegetation or structures." Much of Snodgrass Mountain contains evidence of past or current landslide features and this is the focus of the majority of the analysis of the mountain.

The term "landslides" is a broad category of slope failures that includes slumps, earthflows, debris flows, and rockslides, depending on the nature of the materials involved in the movement and the amount of water involved. Slumps and slides tend to involve more solid material, while flows tend to contain water that fluidizes the soil/rock mass. Smaller slope failures potentially impact structures and roads on a ski area, as well as the appearance and gradient of the slope. Additionally, a slide affects the stability of the hillside above the slide, as the resulting escarpment creates an oversteepened slope. Larger slope failures have the potential for more dramatic slope changes and loss of infrastructure.

B. **Debris Flows/Mudflows –** These are areas defined by Soule (1976) as "areas subject to rapid mud and debris movement after mobilization by heavy rainfall or snowmelt runoff. The essential element of these areas are (1.) a source of mud and debris, usually in the upper reaches of a drainage basin or its contiguous sideslopes; (2.) a drainageway or channel down which this mud and debris move; and (3.) a debris or alluvial fan formed by successive episodes of deposition of mud and debris." In the classic sense, debris flows or mudflows travel down drainages or avalanche paths, as they tend to be fluidized events relating to super saturation. Some previous authors have referred to debris flows or mudflows on Snodgrass Mountain and Mount Crested Butte, but they generally are referring to earthflows, a form of landslide rather than water-born event. There are no mudflow or debris flow deposits mapped on Snodgrass Mountain. However, during heavy runoff events, debris flows and mudflows should be expected in the drainage channels to a limited extent. This debris would be carried to the toe of the slopes in the areas beyond the Forest Boundary.

C. **Rockfall –** The RCE (1995) report identifies areas of bedrock outcrop and potential rockfall hazard. These are mostly small, isolated areas on the west and north slopes of Snodgrass Mountain. There are also a few small outcrops identified near the southwest edge of the southeastern slope of the mountain. Rockfall hazard poses problems mostly from the standpoint of summer use maintenance on access roads and trails. As such, it can be locally mitigated when actual road and trail alignments are evaluated.

D. **Flooding –** Flooding could potentially occur along the small, Unnamed Drainage that drains the mountain during intense summer thunderstorms or rapid spring snowmelt. Although the local drainages are not large, flooding of these channels could cause erosion, undercutting of slopes, and destabilization of structures such as lift towers located near them. Modeling of flood events is recommended to determine the level of flooding hazard, how to protect structures and roads from flooding, and to identify areas where mitigation of flooding is necessary.

E. **Avalanche –** Other than localized slips that can be avoided with proper ski area design and snow maintenance, the only area with avalanche potential is the steep north slope of Snodgrass Mountain. Mears (1979) and RCE (1995) indicate several chutes with high snow avalanche hazard on this slope. Only a small portion of this area is slated for development of ski runs, but careful design and snow maintenance could reduce this hazard.

F. **Expansive Soils –** The soils in the upper portion of the mountain, which is capped by quartz monzonite intrusive rock, are generally rocky, granular and well-drained. The lower slopes of the mountain, which is underlain by Mancos Shale, contains heavy clay soils that are generally fine-grained, moderately to highly plastic, and are poorly-drained. The subsurface testing presented in the RCE (1995) report, indicates that most of the soils tested were clayey, have low to high plasticity, and were highly variable. This indicates that both the Mancos Shale-derived soils and the more highly weathered quartz monzonite intrusive rock weathers to clays with sufficient exposure to moisture. Site-specific testing would be needed at foundation sites for lift towers and other structures to determine the degree of swelling potential for the foundation soils. Engineered foundation systems are likely on these soils, which is not uncommon for the area.

G. **Wetlands/Shallow Groundwater –** As shown on Exhibit 1 of the RCE (1995) report, there is an extensive network of wetlands delineated by Pioneer Environmental Services throughout the proposed ski area. Associated with these wetlands and drainages are areas of shallow groundwater which can be problematic from the standpoint of saturated soils that can lead to slope instability. Areas that topographically trap surface water and groundwater allow for the infiltration of water which can lubricate and weaken soil and rock masses. Wetland areas are protected by Federal law and permitting for construction that may impact wetlands is administered by the U.S. Army Corps of Engineers. Wetland areas would need to be protected from erosion, sedimentation, trampling, or any activities that may disrupt the plant community, soil conditions, or hydrology of the wetland community. Generally, liftlines can span a wetland area or drainage from higher ground, but roadways and ski runs would need to be designed to allow for drainage and so that runoff from these areas do not contaminate the wetlands. It is understood that wetland protection and mitigation will be handled under separate reports.

H. **Erosion –** Due to the clayey and cohesive nature of the soils, erosion is not a huge concern at this site. However, when the soil is exposed in steep escarpments, such as at the face of landslide scarps, some erosion is inevitable in the form of rills and small gullies. The amount of soil loss in these areas is minimal and the surface can be protected with a geogrid or other erosion-control fabric. Also, cut banks during floods can cause erosion due to the exposure of fresh soil. The protection of exposed stream banks with riprap or other erosion mitigation measures in localized areas would be sufficient for erosion control.

I. **Seismic –** The risks to ski areas from earthquakes are damage to structures and the reactivation of landslides, especially saturated slopes. According to the *Gothic* and *Oh-Be Joyful Geologic Maps* (Gaskill, 1991 and 1967), there are five faults or lineaments (observed on aerial photographs) mapped on Snodgrass Mountain within the quartz monzonite porphyry bedrock. They are oriented in the northwest and northeast directions, typical of fractures and dikes formed during the Tertiary volcanic period and subsequent regional uplift. However, none of these are identified as being geologically recent (Quaternary-aged) or potentially active faults (Kirkham and Rogers, 1981; Widmann et al., 1998). Not all faults are indicative of earthquake potential and not all earthquakes produce surface ruptures, but historic records of earthquakes and evidence of geologically recent (Quaternary) faults are good indicators of earthquake potential.

Crested Butte is located in Western Mountain Seismotectonic Province in Colorado, where maximum credible earthquakes are estimated to be on the order of magnitude 6 to 6.5, which is equivalent to Modified Mercalli (MM) VI to VIII (Kirkham and Rogers, 1981). The Colorado Geological Survey indicates that, based on limited historical records, Colorado is considered to be a region of minor earthquake activity, where moderate to large events are relatively infrequent. However, there is a growing body of evidence that suggests that Colorado is at greater risk than previously thought. According to the Uniform Building Code, western Colorado is in Seismic Risk Zone 1 where distant earthquakes would be expected to cause only minor damage to structures with fundamental periods of vibration greater than one second. Excepting transmission towers, there are no such tall, slender structures in western Colorado. However, the CGS recommends in their Bulletin #43 that a Seismic Risk Zone 2 designation may be more appropriate for all of Colorado except the extreme northeast corner. It also suggests that a minimum 0.1g horizontal acceleration be used in design and safety analyses for areas that are distant from known active faults. According to the Irish (1996) report, earthquake-induced peak accelerations on the order of 0.05 g are not expected to be exceeded in the next 50 to 100 years at this site.

V. LANDSLIDES/SLOPE MOVEMENT ANALYSIS

This section describes the nature of the landsliding that occurs on Snodgrass Mountain and provides detailed descriptions of the major Geologic Hazard Units (GHU's) that this current study delineated and evaluated.

A. Nature of Landslides on Snodgrass Mountain

Except for the gentle terrain near the top of the mountain, large portions of the remaining slopes either have evidence of older landslide movement or have similarities (composition, aspect, etc.) to slopes with recently active landslides. The lower slopes surrounding Snodgrass are composed of unconsolidated material including landslide deposits, colluvium, alluvium, talus and glacial moraine material over Mancos shale. The types of slope movement on Snodgrass Mountain include rock and soil slumps, earthflows, debris flows, debris or rock slides, debris avalanches, rock falls and soil creep. According to all the previous studies, the most active region of the mountain is the lower southeast slope. This is likely due to the larger valley glacier that deeply scoured the East River valley to the east of Snodgrass Mountain, creating asymmetrically over-steepened slopes on that side of Snodgrass. The valley glacier on the west side of Snodgrass, within the Washington Gulch drainage, was a much smaller glacier and therefore did not scour the slopes as significantly as on the east side. Also, there is one major drainage channel (herein called the Unnamed Drainage) that drains Snodgrass Mountain and it flows from a bowl near the summit down to the southeast towards the most active region of the mountain, the lower southeast slope.

The RCE (1995) report emphasizes the role that groundwater plays in the failure of slopes and that report states that "In terms of the mechanics of landsliding, water in the upper slopes adds to the weight of the driving forces and in the lower slope, significantly reducing the shear strength of the resisting forces." When a slope failure occurs, weight from the upper slopes of the slide are transferred to the lower slopes and a more stable gently-sloping surface results. The slide material in the lower portion of the slide applies passive pressure to (or buttresses) the toe of the slope, making a more stable condition. However, a slide can also expose a steep escarpment at the head of the slide that is no longer supported, creating an unstable condition. Eventually, due to gravity and pore pressure from groundwater that lubricates and weakens soil materials, the slope above the slide will fail. This uphill progression of slides is called retrogressive failure. Slopes composed of clayey soils will become flatter with time due to this intermittent sliding.

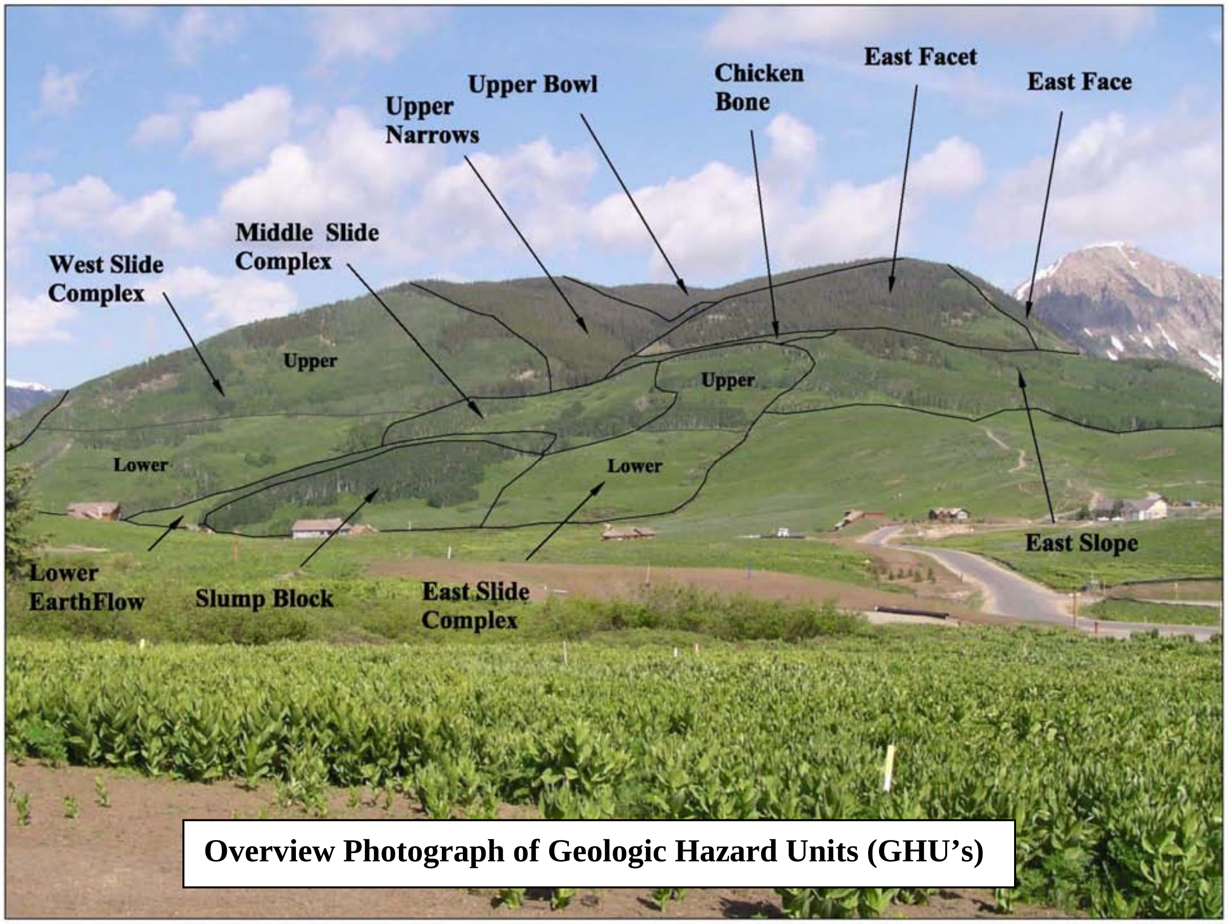
The largest area of obvious landslide movement is located on the lower southeast slopes of Snodgrass Mountain. Previous investigators (see Section III) have referred to parts of the slide complex as the West Slide and East Slide and Baum (1996) added to those two designations an area called the Slump Block. A slide complex consists of many adjoining and overlapping slumps, translational slides and earthflows. Because of its complexity, any reasonably practical subdivision of the slide components is to some extent arbitrary, but necessary for an evaluation of the extent, age and nature of slope movement. For continuity, this report has retained the three units used by Baum (1996), but has added an area between the East and West Slides, named the Middle Slide Complex, and an area between the West Slide and the Slump Block, named the Lower Earthflow. These subdivisions in categories were due to the presence of different landforms, processes, geologic hazards, and composition. Also, because of the complex nature of landsliding, some previously discussed landslides were divided into the source area (zone of depletion) and displaced material (zone of accumulation) because their processes and possible mitigation are generally different. For example, the West Slide Complex was divided into the Upper West Slide Complex and the Lower West Slide Complex and the East Slide Complex was divided into the Upper East Slide Complex and the Lower East Slide Complex. In addition, the West Face was divided into North and South components based on landform and hazard differences.

B. Geologic Hazard Units (GHU's)

In the course of this investigation, 13 main Geologic Hazard Units (GHU's) with three of these units split into sub-units, for a total of 16 distinct GHU's, were identified by topography, geomorphic features and geologic setting. Each of these units will be discussed below and they are summarized in Table 1 (page 14) by name, landform, important features, and age classification (McCalpin: 1984). Some of these GHU's were identified by other authors and further evaluated herein, some were further subdivided into smaller units with distinctive features, and others are newly defined areas identified during this study. An effort was made to keep the names of the regions the same as or similar to previous work to reduce confusion.

Each polygon that defines the boundaries of a GHU represents a general collection of similar landforms. As such, the presence of active landslide features within a GHU may not be representative of the entire GHU. In other words, just because a GHU has some active landslides does not mean that the entire GHU is "filled" with these features. Also, since each GHU represents a complex area with a variety of features, the GHU's are not uniform in terms of overall hazards or age classification. However, each GHU has generally similar landform features which allow them to be identified collectively.

The following photograph, taken of the southeastern slopes of Snodgrass Mountain, shows most of the Geologic Hazard Units discussed in this report. There are additional ground photographs presented under each GHU (discussed after Table 1) and in Appendix C (with 130 photos). Map 5 (Appendix A) shows the locations and orientations of the ground photographs.



Overview Photograph of Geologic Hazard Units (GHU's)

Map 2 shows the GHU's on Snodgrass Mountain on a topographic and orthophoto base map. This map also shows the ski area boundary for the "Alternative 3" proposal. For ease of viewing, Map 2 has been divided into three smaller maps superimposed on topography and orthophotos: Map 2A is the lower mountain (GHU's #1 though 5), Map 2B is the middle portion of the mountain (GHU's #6 through 8 and 12), and Map 2C is the upper, western and northern faces of the mountain (GHU's #9 through 11). GHU #13 (Unverified Areas) is found on small portions of all three maps (2A, 2B, and 2C).

Table 1. Summary of Geologic Hazard Units (GHU's)

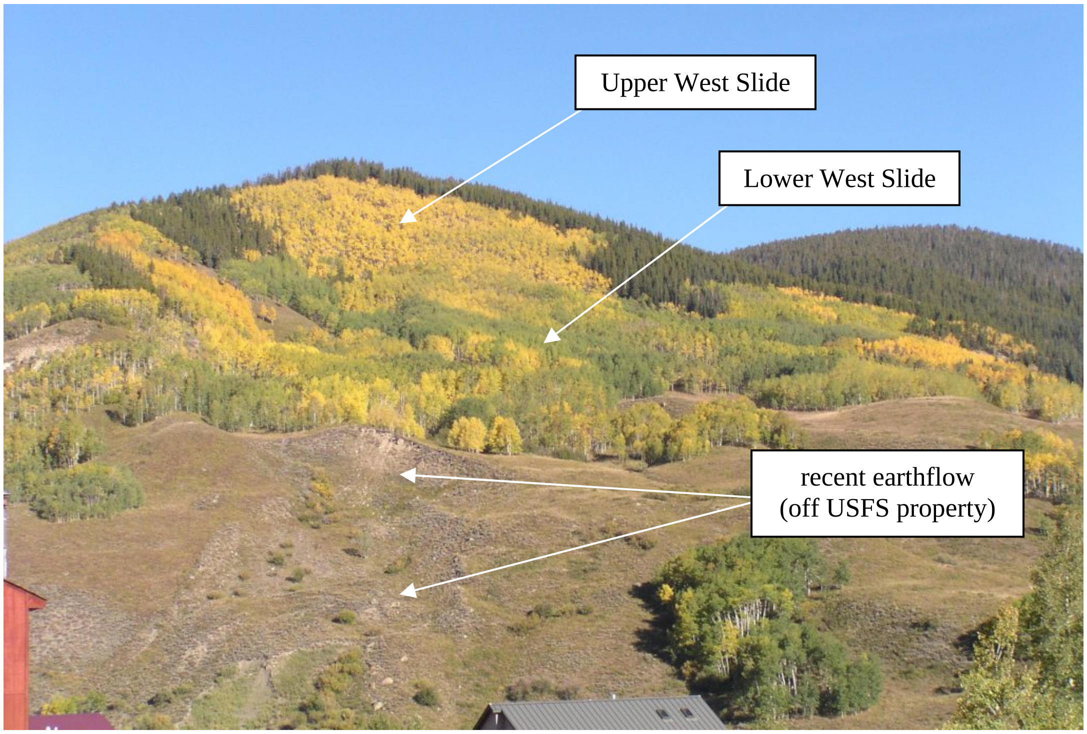
# of GHU	Name of GHU	Landform/Composition	Characteristic features	Age Class*
1A	West Slide Complex Upper	landslide source area; quartz monzonite bedrock and colluvium	steep igneous bedrock scarp; landslide blocks; bedrock shear zone; steep slopes; rejuvenated bank erosion	1-2
1B	Lower	landslide depositional area underlain by shale	extensive wetlands; earthflows; hummocky terrain; sag ponds; retrogressive failures; disrupted/irregular drainage	1
2	Slump Block	landslide slump blocks in displaced shale	extensive wetlands; retrogressive failures; hummocky terrain; irregular drainage; eroded scarp upslope	1
3	Middle Slide Complex	landslide slump blocks and earthflows in shale	extensive wetlands; disrupted drainage; retrogressive failures; undrained depressions; topographic benches	1-2
4	Lower Earthflow	earthflow	lobate form; parallel drainages; high water table; low gradient; hummocky topography	1-2
5A	East Slide Upper	landslide source area; shale bedrock with cover of colluvium and glacial debris	two arcuate scarps at head; topographic benches (aligned scarps and slump blocks)	1-2
5B	Lower	landslide depositional area; deep colluvium over shale	hummocky terrain; shallow scarps; displaced fences; rejuvenated drainages	1
6	Chicken Bone	glacial moraine colluvium over shale	gentle hummocky terrain; slumps; springs; meadows; vegetated scarps; wetlands	1-2
7	East Facet	quartz monzonite bedrock with talus and colluvium	soil creep; small old rotational slides (locally hummocky); steep slopes	2 (locally 1)
8	Upper Narrows	quartz monzonite bedrock with talus and colluvium; some shale near bottom of unit	arcuate slumps; earthflow impinging on drainages; bent trees; arcuate forested blocks; steep slopes	1-2
9	Upper Bowl	quartz monzonite bedrock with talus and colluvium	heavily wooded; bowl-shape with moderate slopes	3-4
10A	West Face North	quartz monzonite bedrock on upper slopes, shale on lower slopes; talus, colluvium, moraine	some rock outcrops with talus; steep slopes; heavily wooded with conifers	2-3
10B	South	colluvium over shale	widespread soil creep, some accelerated; displaced fence; slumps, earthflows at bottom; mostly aspen	1-2
11	North Face	quartz monzonite scarps on upper slopes, colluvium and glacial debris over shale on lower slopes	rotational/translational slide failures near crest; soil creep; rock outcrops and talus; some chutes; steep slopes	1-3
12	East Face	glacial moraine and colluvium over shale	slump blocks in shale; smaller slumps transitioning into earthflows; sag ponds, wetlands, hummocky topography	1-2
13	Unverified Areas	similar to adjacent GHU's #1A, 8, 9, 10A and 10B	similar to adjacent GHU's #1A, 8, 9, 10A and 10B	1-4

*Age Class convention was used according to McCalpin (1984):
Age Class 1 = "Active" (<100 years); 2 = "Inactive – Young" (100 to 5,000 years); 3 = "Inactive – Mature" (5,000 to 10,000 years); 4 = "Inactive – Old" (>10,000 years)

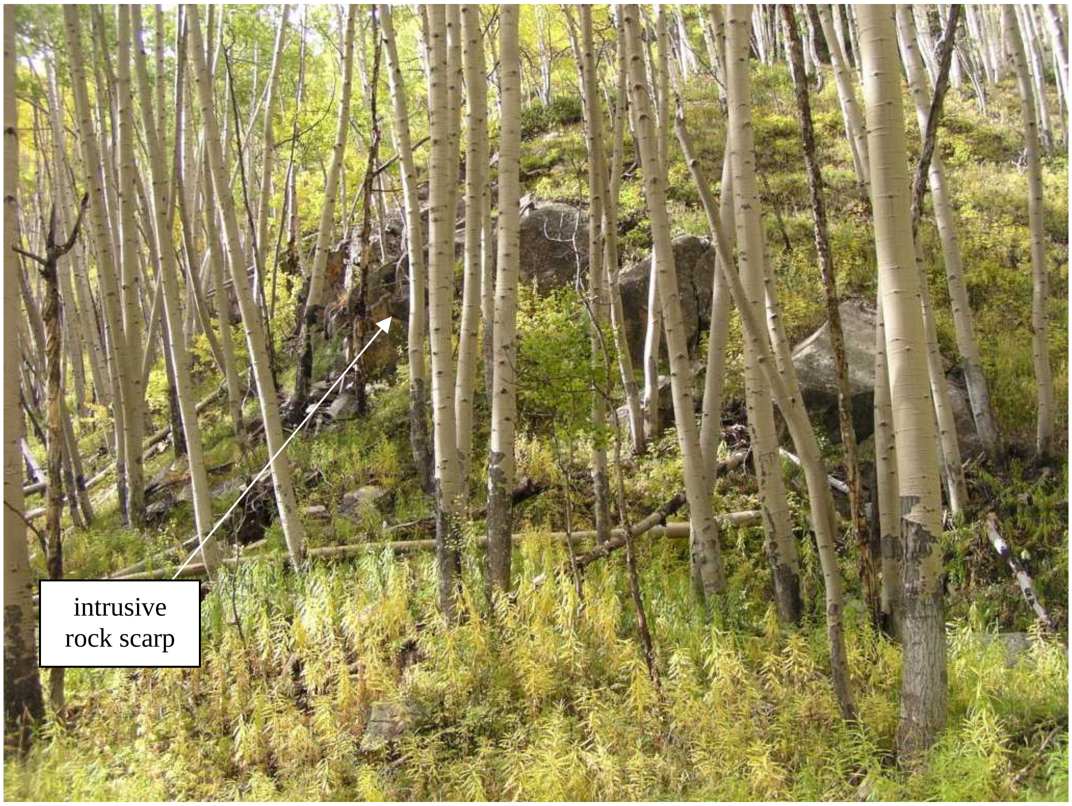
1. West Slide Complex (Upper and Lower) – GHU #1A and #1B

The West Slide Complex (GHU#1) is located southwest of the Unnamed Drainage that separates the two southeast trending ridges off of the Snodgrass summit (see Overview Photograph on page 13 and Maps 2 and 2A). There are 22 ground photographs of the West Slide Complex presented in Appendix C as photos WS01 to WS22. See Map 5 (Appendix A) for locations and orientations of these photographs.

The West Slide Complex extends from just below the false summit on that ridge to the valley bottom between the Crested Butte ski area and the proposed Snodgrass Mountain development. The West Slide Complex consists of two components: the Upper West Slide (also known as the West Facet for its triangular-shaped cut face) and the Lower West Slide. The upper and lower components of this slide are shown in the following photograph. The recent (within past 40 years) earthflow discussed in the Baum (1996) report can be seen in the lower left quadrant of this photograph, but it is outside of the USFS boundary.



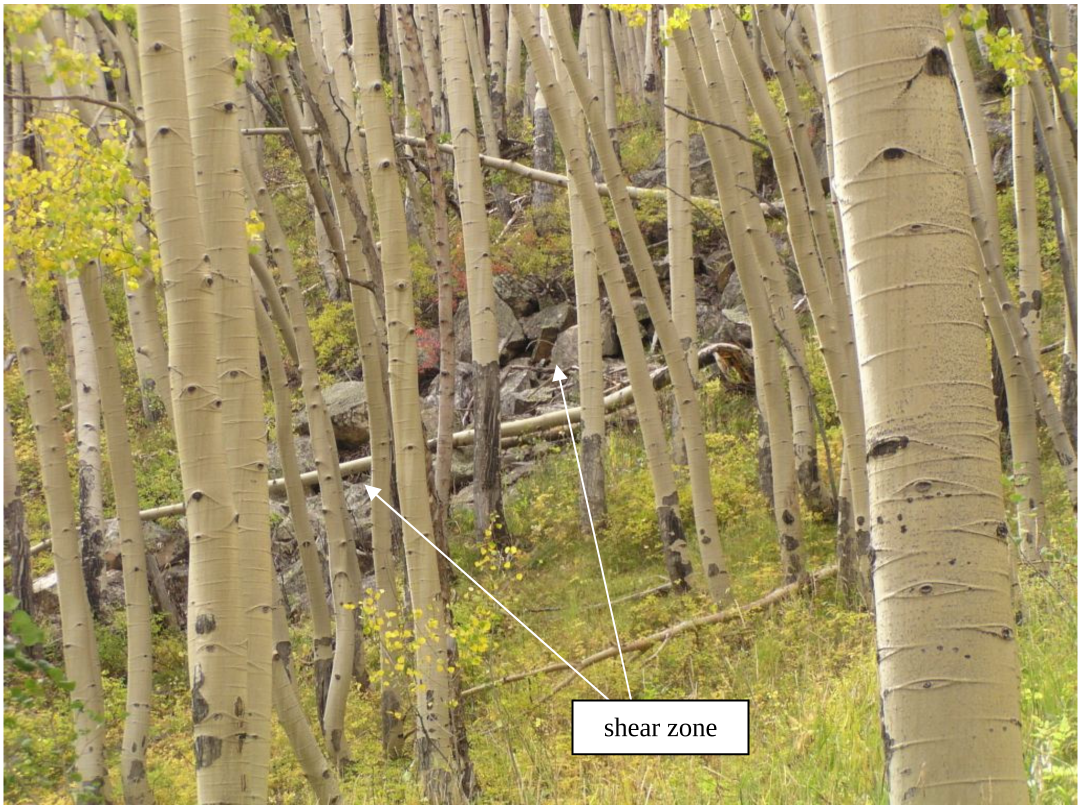
The Upper West Slide is bowl-shaped and it appears that a massive landslide originated at this location and deposited much of the soil and rock that forms the Lower West Slide. It is called the "Landslide Evacuated Area" by Irish (1996) and RCE (1995) mapped a continuous scarp along the sides and rim of this slope, supporting this interpretation. The bowl is characterized by steep scarps, some with sparse vegetation and slump blocks. These slide features developed after the major slide event suggested above. Baum (1996), based in part on the USGS geologic mapping (Gaskill, 1991), mapped the top of the West Slide at the top of ridge, which includes the more obvious of these more recent features. Towards the upper part of the slide, intrusive igneous rock is visible in the scarps, as seen in the following photograph (el. 10,250'). Upslope from the larger scarps at the head of the slide are small scarps and evidence of rapid soil creep indicating that retrogressive failure up the slope is occurring.



The Lower West Slide is hummocky and formed primarily by earthflows with some slumps and undrained depressions. On the southwest side of the Unnamed Drainage there is an active earthflow (outside of the USFS boundary) that is located between the Lower Earthflow (GHU #4) and the Lower West Slide (GHU #1).

The failure surface for the West Slide Complex is on Mancos Shale and probably quite deep for most of the complex. This is a complex series of "nested" and retrogressive slides, with some being block failures and others exhibiting earthflow features. Surface drainages have been disrupted and modified both in plan and profile by slope movement. At one location in the Lower West Slide (el. 9,935'), recent erosion through a hummock with leaning trees has created steep cut banks. Fresh cracks in the soil and igneous rock, without much infilling by forest debris, were observed at several locations, which indicates slope movement within the past few years. In some cases, surface water was flowing along the cracks and the channel banks were vertical, also indicating recent slope movement.

There were two areas of recent shear zones observed in the Upper West Slide. These shear zones, based on the small amount of leaves and litter between the fractured rocks, may have occurred within the past several years. Just to the east of the rock scarp shown in the above photograph (el. 10,200'), there is a fresh 25-foot-wide shear zone that extended about 100 feet uphill. This shear zone is shown in the following photograph.



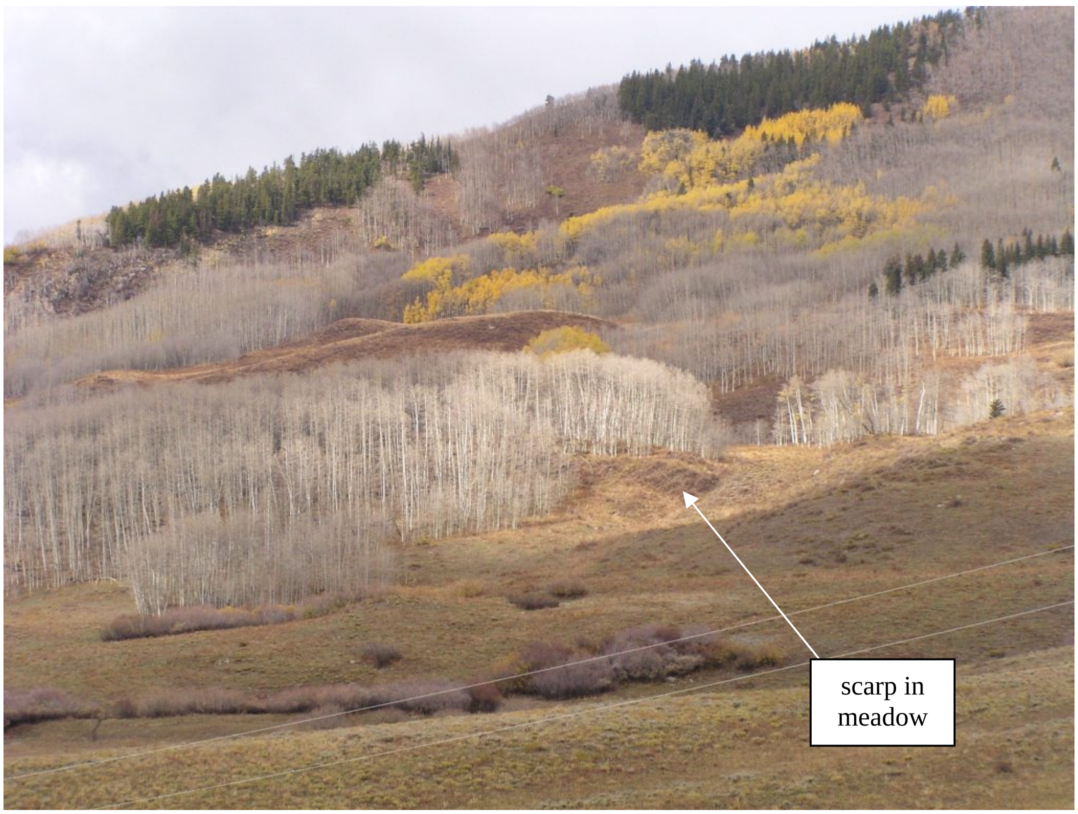
Another recent shear zone in rock is in the upper portion of the Lower West Slide (el. 9,850'). The recent slide described by Baum (1996) as having been active in the past 40 years and shown in the lower left quadrant of the photograph on page 15, is downslope from this shear zone.

Leaning and bent trees are common across much of the Upper and Lower portions of the West Slide Complex, indicating that the much of this complex slide has moved within the past 100 years and can be classified as active (McCalpin, 1984). Some of the deformation of the tree trunks is obvious and some is more subtle to the untrained eye. Additionally, the examples of recently disrupted surface drainage, unvegetated shear zones, and fresh cracks indicate portions of the slide complex have moved even more recently, probably within the past few years. Landslides such as earthflows do not move uniformly at the same time and strong evidence of localized movement supports considering the entire GHU to be only marginally stable. Also, slides such as earthflows can be moving slowly without any cracks visible on the surface (Baum, 1996).

2. Slump Block – GHU #2

The Slump Block (GHU #2), named and identified as a landslide by Baum (1996), is located downslope of the Middle Slide Complex and roughly between the West Slide and East Slide Complexes. It is largely forested, with areas of open meadows (see Overview Photograph on page 13 and Maps 2 and 2A). There are 5 ground photographs of the Slump Block presented in Appendix C as photos SB01 to SB05. See Map 5 (Appendix A) for locations and orientations of these photographs.

The Slump Block and West Slide Complex are separated by the Lower Earthflow and an Unnamed Drainage. To the northeast, the Slump Block adjoins and is partially covered by the earthflow portion of the Lower East Slide, making movement of the Slump Block older. The source area is probably from the northwest where large, clearly-defined scarps are still evident in the lower part of the Middle Slide Complex and the Lower West Slide. The surface is hummocky with numerous old scarps and leaning and curved aspen. On aerial photographs, the tree canopy appears irregular and mottled. To the north of the forested portion of the Slump Block, there is an undrained depression formed by a smaller slump. Surface runoff has eroded a small steep gully in the slope below the depression, exposing bare soil. This slope is part of a scarp that starts in the meadow and extends into the aspen, as seen in the middle of the following photograph.



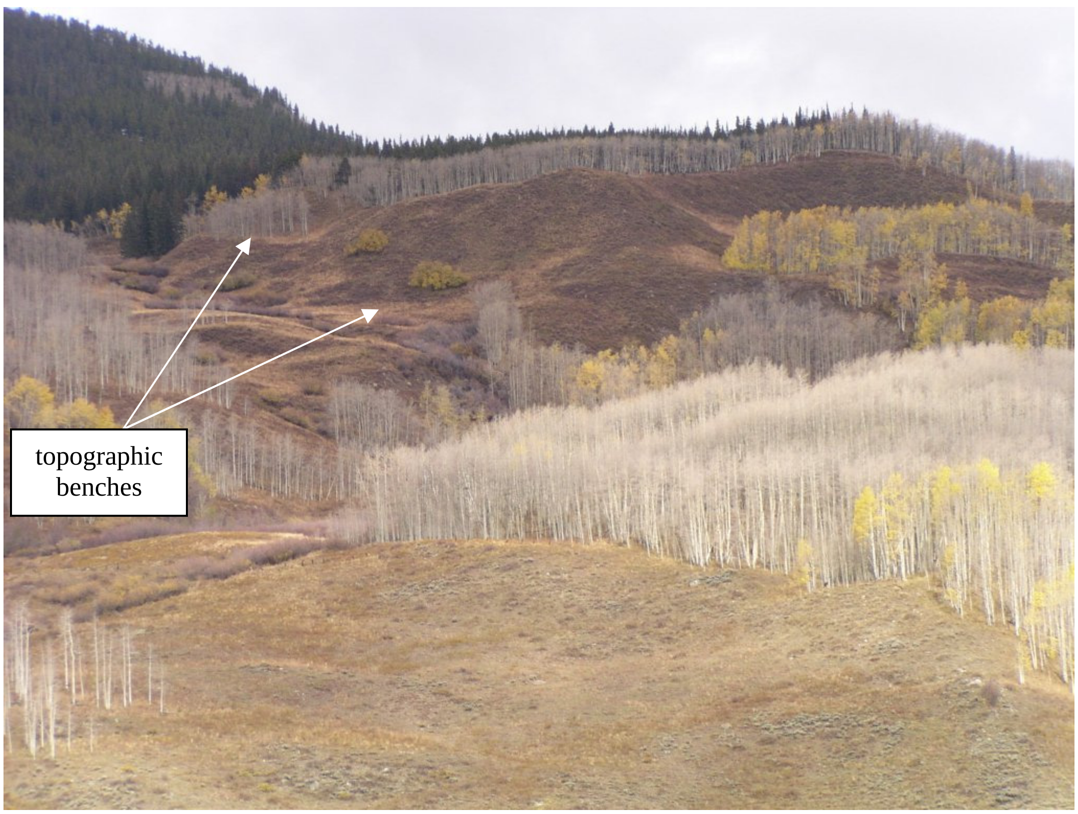
Both on and below this scarp there are numerous leaning trees. Near the northern edge of the Slump Block and adjacent to the Lower East Slide (el. 9,650’) there is a ranching fence that is clearly bowed in the downhill direction. Some of the posts have been nearly pulled to the ground by tension on the wire. Based on the displacement of the fence, undrained depressions, and the leaning trees, this slump on the larger Slump Block is considered active (less than 100 years old).

It is not likely that the Slump Block will move en mass, but based on the easily identifiable slump scarps, hummocky topography, disrupted drainage, leaning trees and mottled tree canopy, most of the slopes of the Slump Block should be considered only marginally stable and future localized failures are likely, and more likely with disturbance.

3. Middle Slide Complex – GHU #3

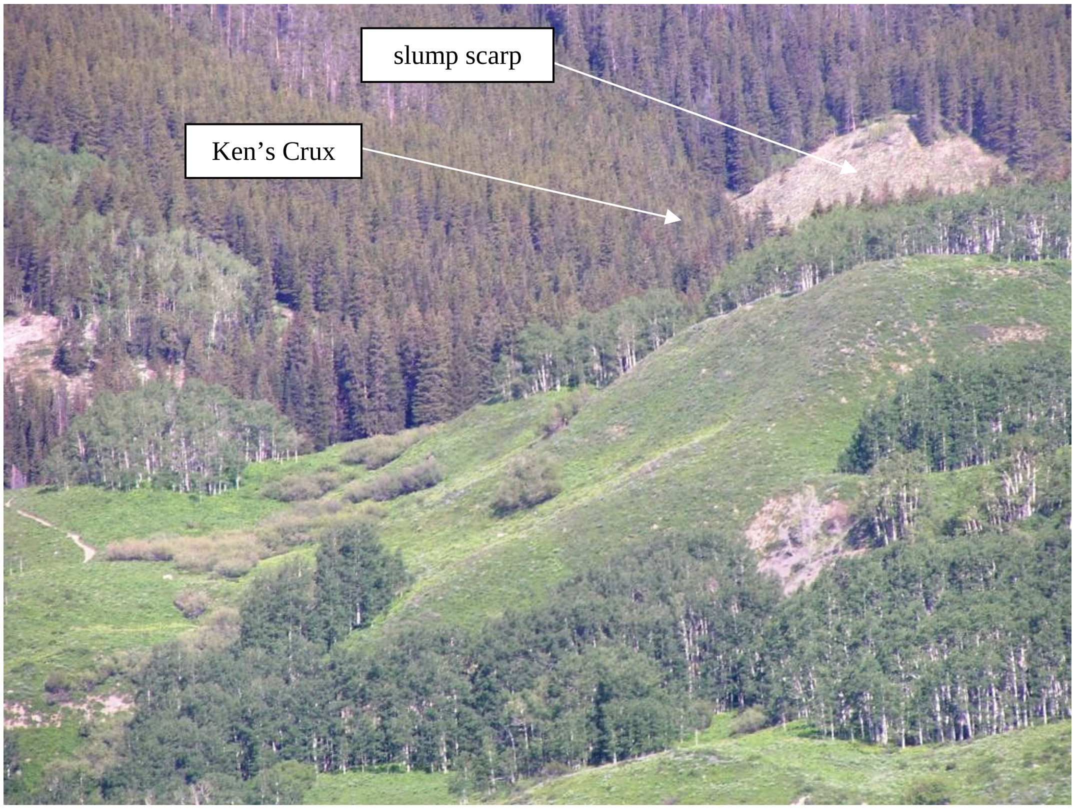
The Middle Slide Complex (GHU#3) is located east of the West Slide Complex and Unnamed Drainage, west of the East Slide and north of the Slump Block and Lower Earthflow (see Overview Photograph on page 13 and Maps 2 and 2A). There are 16 ground photographs of the Middle Slide Complex presented in Appendix C as photos MS01 to MS16. See Map 5 (Appendix A) for locations and orientations of these photographs.

RCE (1995) and Irish (1996) included the Middle Slide Complex as part of the East Slide and Baum (1996) as part of the West Slide. Primarily for convenience in preparing the risk assessment, but also because of some differences in the nature of the landslides from the other areas, the Middle Slide Complex is treated as a separate unit. It consists of numerous scarps and associated slump blocks that, in some cases, transition into earthflow deposits. A series of retrogressive scarps and slump blocks characterized by topographic benches extend up the slope along the northeast side of the Unnamed Drainage, as seen in the following photograph.



Wetlands with poor surface drainage and at least one undrained depression are in this area. Movement of these landslides has been towards the southeast. This series of scarps and slump blocks is roughly parallel to the Unnamed Drainage and the Lower Earthflow. Steep scarps in shale are not stable over the long term and it is probable that this series of slides, through renewed movement, will become an earthflow complex similar to the East Slide Complex.

Several slumps at the head of the Middle Slide Complex have moved to the south towards the Unnamed Drainage. The scarps with the least vegetation are the lowest in elevation and probably the most recent. Several of these scarps and the associated slides, including one with the prominent bare spot (shown in the following photograph), have removed material from the East Slide Complex.

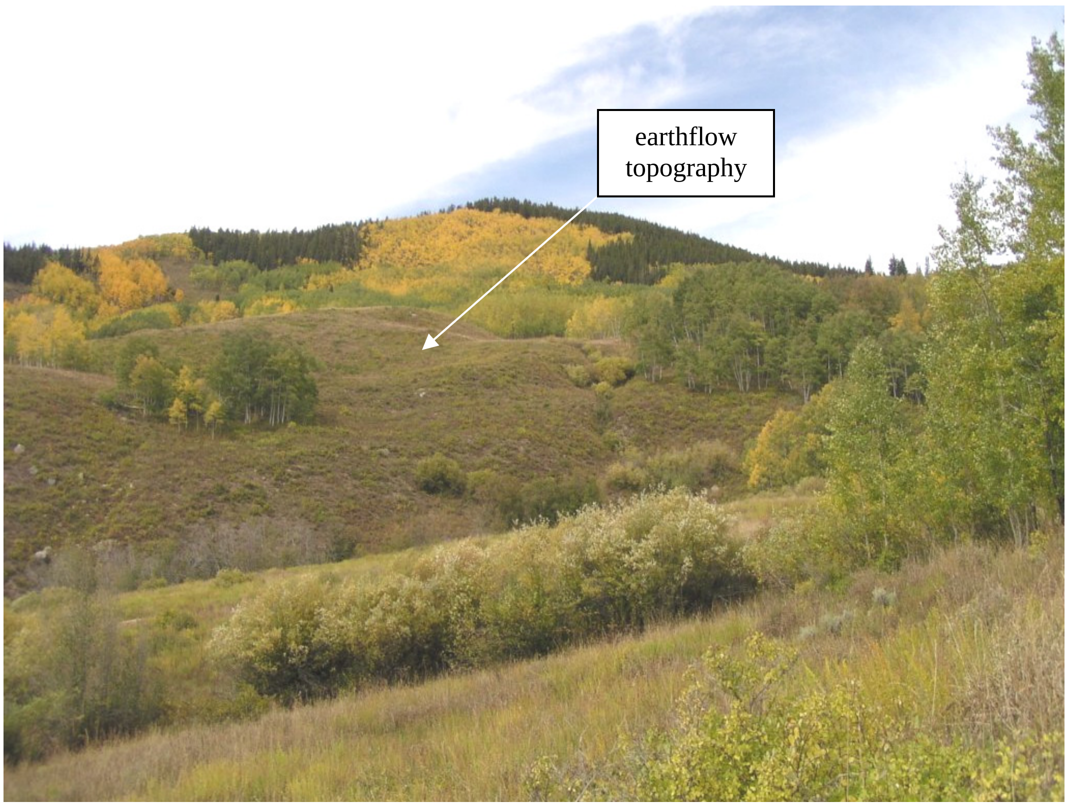


At the uppermost end of the Middle Slide Complex, the Unnamed Drainage leaves a narrow area informally named Ken's Crux (because of the terrain restrictions and likely high concentration of skiers). The slope to the left looking upstream is steep and underlain by fractured intrusive igneous rock of the laccolith. There are springs at the base of this rocky slope. The slope on the right of Ken's Crux is the lateral scarp of a south trending slump. There is a small rock slump in the lateral scarp that moved perpendicular to the orientation of the lateral scarp. The leaning young aspen and the fresh cracks on the slide mass are evidence that the rock slump has moved recently. There is a thin bed of intrusive igneous rock, probably a sill, that outcrops part way up the head scarp of the large slide, and the rock that failed on the lateral scarp probably was similar. Leaning trees on the lateral scarp, just up the hill from the rock slump, support the hypothesis that the lateral scarp material had recently slid downhill towards the stream on top of the contact with shale bedrock. The fresh cracks in the rock slump and the small size of the bent and leaning aspen on the slope above suggest that these slopes have moved within the last 25 to 50 years or, perhaps, more recently. Further upslope from this narrow section of the valley and the lateral scarp there were numerous leaning trees in a conifer stand indicating slope movement but no cracks were observed in the ground surface.

4. Lower Earthflow – GHU #4

The Lower Earthflow (GHU #4) is located between the Slump Block and the steep slopes at the base of the West Slide and Middle Slide Complexes (see Overview Photograph on page 13 and Maps 2 and 2A). There are 4 ground photographs of the Lower Earthflow presented in Appendix C as photos LE01 to LE04. See Map 5 (Appendix A) for locations and orientations of these photographs.

The ground slope on the Lower Earthflow varies but is generally under 20% down to the south and southeast. Evidence that this unit is an earthflow includes a plant community indicative of a high water table, low gradient hummocky surface, lobate form, roughly parallel drainages on each side, and the lack of mature aspen and conifers on its surface. Some of these features can be observed in the following photograph, taken looking northwest at the middle portion of the Lower Earthflow.

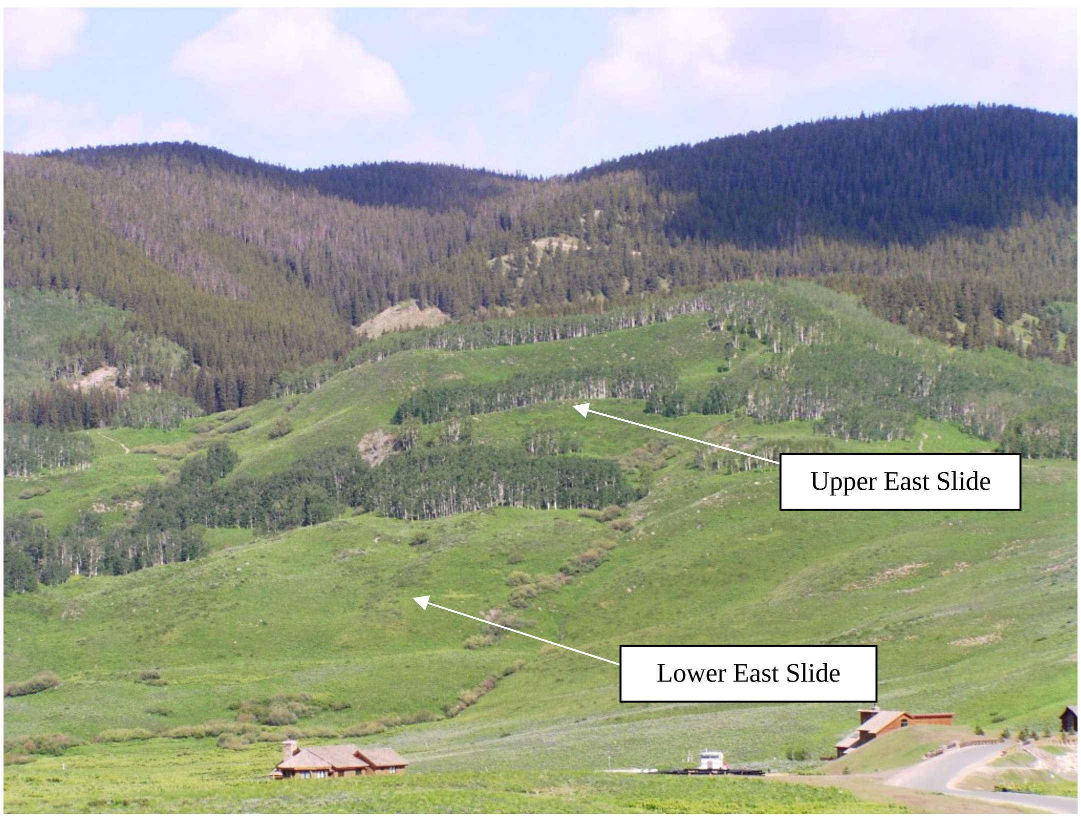


No recent cracks were observed on the surface along two traverses of the slide, which supports but does not prove that the earthflow is not currently moving. Other than the two traverses, this unit was not viewed in great detail on the ground. The lower end of this unit appears to have pushed the stream in the valley bottom against the opposite side. On aerial photos the stream does not appear to have eroded the toe of the slide and the channel gradient upstream from the slide is flatter than downstream. It is not clear whether this large lobe is part of the earthflow that extends upslope between the Slump Block and the Middle Slide Complex or is part of the West Slide Complex. However, in either case, the fresh appearance of the lobe on aerial and ground photos is evidence of massive movement within probably the past few hundred years.

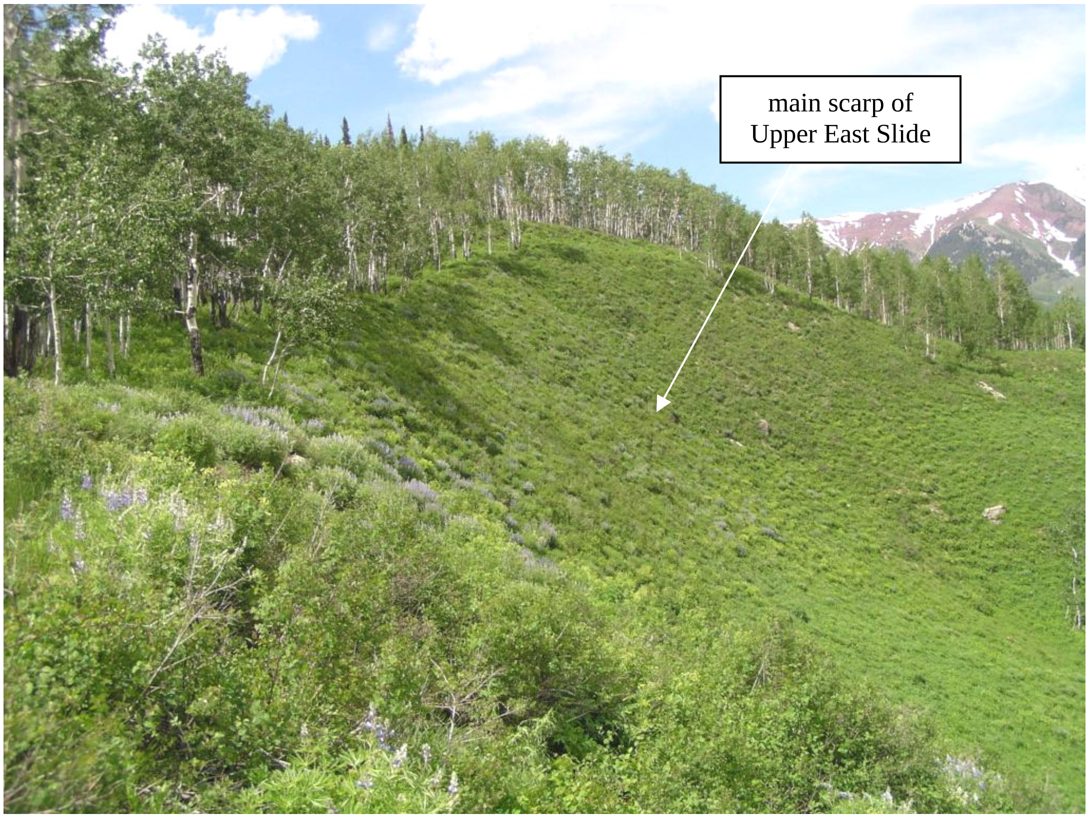
5. East Slide Complex (Upper and Lower) – GHU #5A and #5B

The East Slide Complex (GHU #5) is located on a southeast-facing slope of the lower portion of Snodgrass Mountain toward the northeast edge of the permit area (see Overview Photograph on page 13 and Maps 2 and 2A). There are 12 ground photographs of the East Slide Complex presented in Appendix C as photos ES01 to ES12. See Map 5 (Appendix A) for locations and orientations of these photographs.

The East Slide Complex is northeast of the Middle Slide Complex, Lower Earthflow, and Slump Block and southwest of East Face. Previous investigators (RCE, 1995; Irish, 1996; Baum, 1996) have considered it to be the least stable part of the proposed development and all have recommended avoidance of this area, if possible. Due to its complexity and varying landslide features, the East Slide Complex has been further divided in this study into the Upper East Slide and Lower East Slide. The Upper East Slide consists of a sequence of aligned scarps and slump blocks starting at an elevation of 10,185 feet and descending down the slope. The landslide transitions into an earthflow at 9,810 feet, just below the bottom of a clump of aspen, and it extends to the valley bottom at 9,525 feet. This earthflow portion of the East Slide Complex is the Lower East Slide. The entire East Slide Complex is shown in the following photograph, taken looking northwest from a residential area in Mount Crested Butte.



In the Upper East Slide, a number of secondary slumps have occurred in portions of the main scarps. There appears to be a bench and low scarp just above the top of the uppermost main scarp, which is shown in the following photograph. Some minor soil cracking was observed on this bench. The slump blocks have areas of poorly developed drainage and undrained depressions. It is important to note that within the Upper East Slide (el. 9.960'), McCalpin and Burke observed fresh transverse soil cracks in a topographical trough that was probably formed recently by a rotational slump.

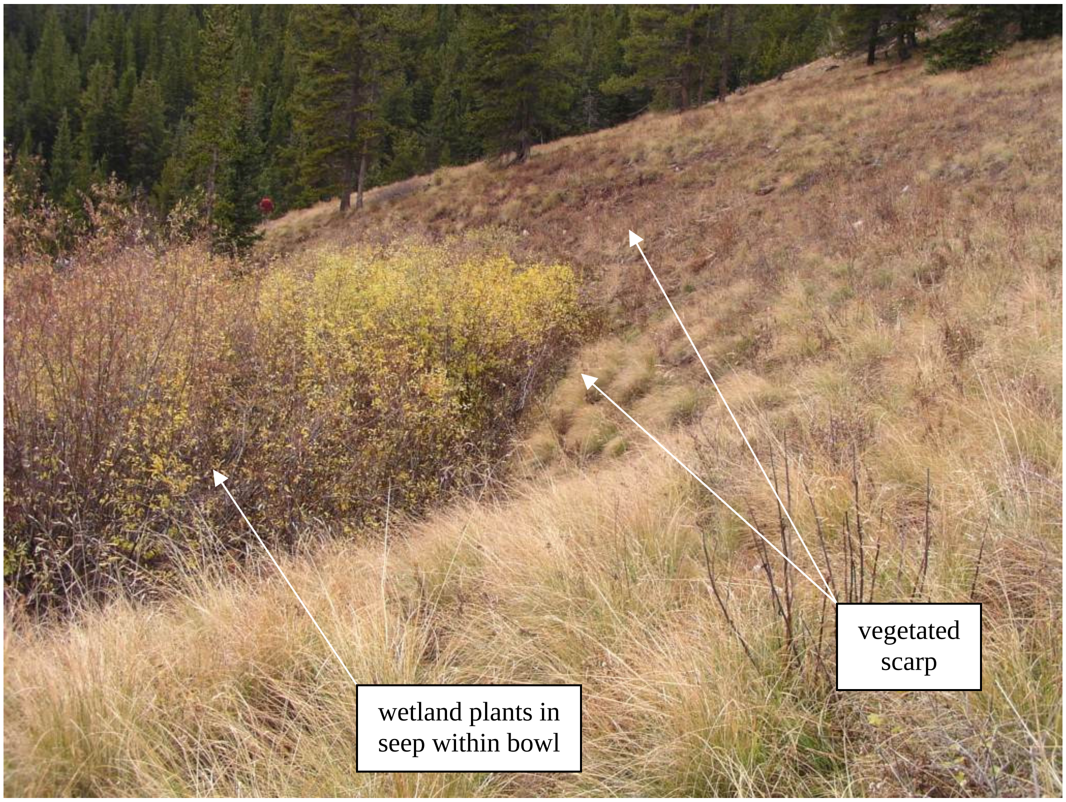


In the Lower East Slide, a fence that crosses the earthflow has been displaced up to 12 feet at two locations. Also, along the northeast side of the slide just downslope from one of the displaced fences (el. 9,750'), the stream has recently downcut into the soil and created a low, near-vertical bank. Both of the above features indicate recent movement of the earthflow portion of the slide, supporting an age classification of active.

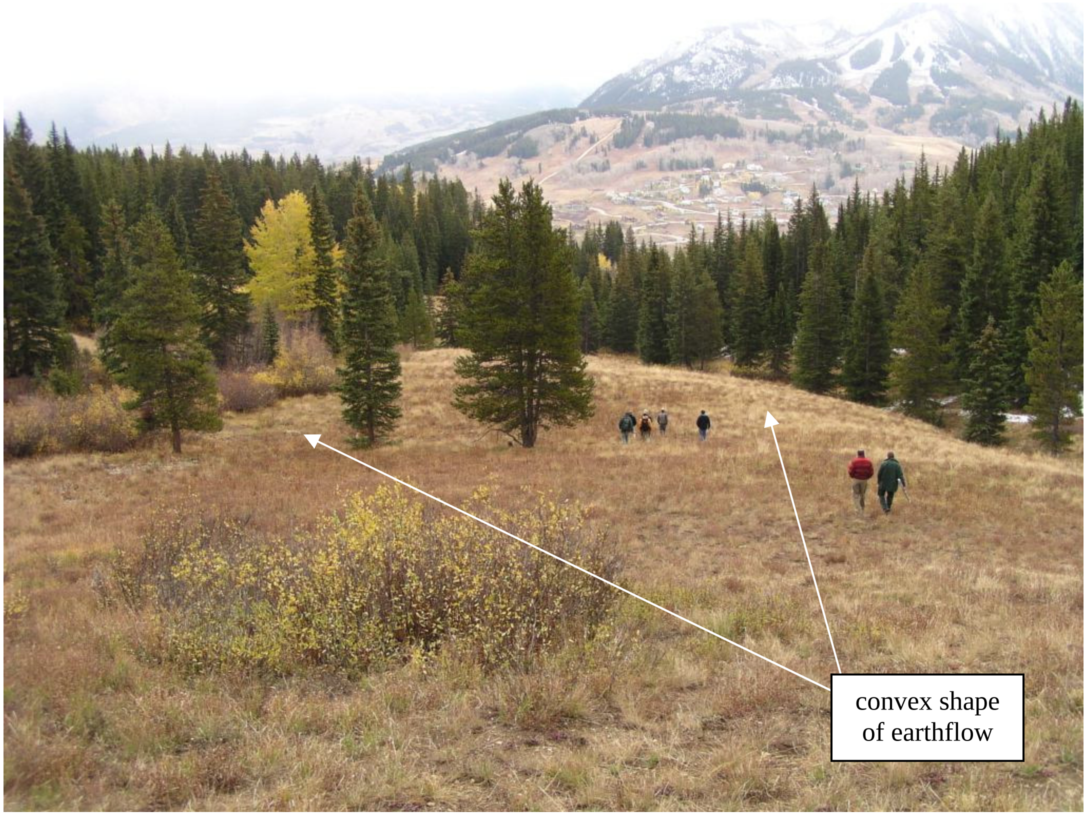
6. Chicken Bone – GHU #6

Above the landslides on the lower southeast slopes, there is an area located roughly mid-mountain called the Chicken Bone (GHU #6), which is characterized by gentle hummocky slopes, meadows, clumps of conifers, wetlands, springs, and slumps (see Overview Photograph on page 13 and Maps 2 and 2B). There are 10 ground photographs of the Chicken Bone presented in Appendix C as photos CB01 to CB10. See Map 5 (Appendix A) for locations and orientations of these photographs.

The Chicken Bone is located northeast of the Unnamed Drainage and upstream from the narrow ravine at the upper end of the Middle Slide Complex (GHU #3). There is subtle morphologic evidence of previous deep movement in the Chicken Bone, but the more recent scarps indicate only shallow movement of the near surface soils over shale. The meadows are hummocky with numerous visible scarps, indicating previous slumping, some of which are probably less than 100 years old. One such vegetated scarp is shown in the following photograph. Note the wetland plants in the bowl of the scarp, suggesting groundwater seepage in this area. Although the Unnamed Drainage was dry throughout the Chicken Bone unit, there is evidence of some springs in the area, such as this one.



The slumps are on relatively low gradient slopes (generally under 20%) with numerous wetlands and seeps suggesting that the underlying bedrock and main sliding surface is shale. Along the west edge of Chicken Bone there are earthflow deposits from slope failures on the lower slope of the East Facet (GHU #7). It appears that most of the Chicken Bone area, as well as some of the upper slopes of the East Face (GHU #12), were formed by deposition from an older massive landslide originating on the East Facet to the northwest. Also, between the Unnamed Drainage and a parallel spring-fed stream to the northeast that originates in the wetlands below the scarp shown in the above photograph, there is a gentle low ridge that has the morphology of an earthflow. This convex-shaped surface bounded by parallel drainages is shown in the following photograph.



Some leaning trees were observed on this probable old earthflow, but no cracks in the ground were seen. Recent, slow movement is likely but major movement may have occurred over 100 years ago and it appears relatively stable. Although scarps and earthflow morphology is present in this unit, they were likely formed during past, wetter conditions.

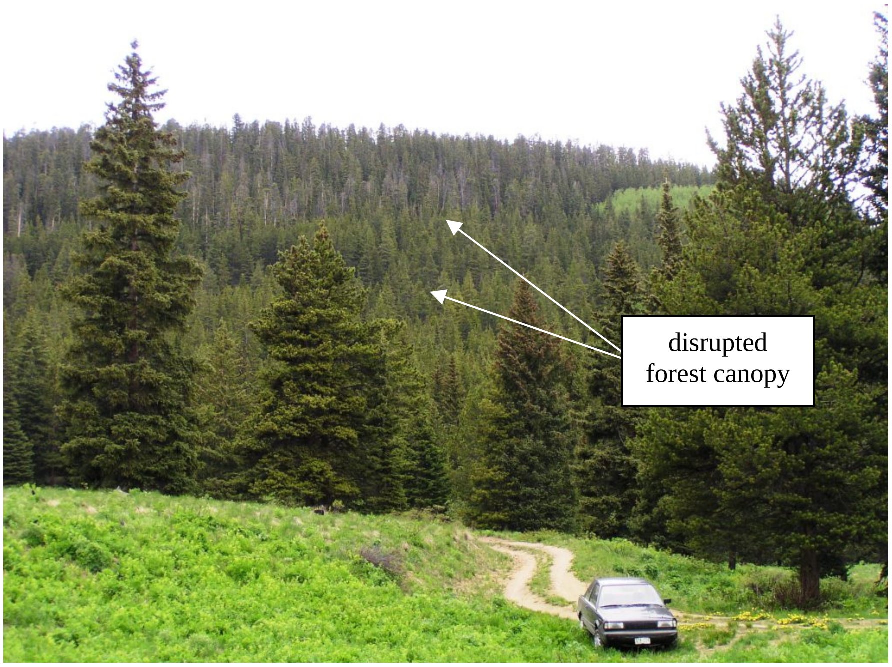
The eastern part of the Chicken Bone unit is thickly forested with mature conifers except for an arcuate open area north of the narrow ravine (Ken's Crux) in the Middle Slide Complex (GHU #3). This open area is clearly seen as an arcuate feature on the detailed topographic map of Snodgrass Mountain (Map 1) near the southeast edge of the unit at an elevation of 10,190 feet. The open area has topography consistent with being an eroded main scarp. It appears that this cleared area is the southeast half of a landslide that has been partially obscured by subsequent slope failures in the more open meadows to the northwest. Aerial photographs show subtle arcuate traces suggestive of slide movement upslope from this probable slide. Also, leaning and bent trees are in this area and the detailed topographic map shows arcuate and hummocky topography. A small stream with low but steep eroded banks and angular changes in direction is located just downslope of this open area. This freshly incised stream is shown in the following photograph. The recently eroded appearance of the stream channel and the leaning trees suggest slope movement within the last 100 years or less.

7. East Facet – GHU#7

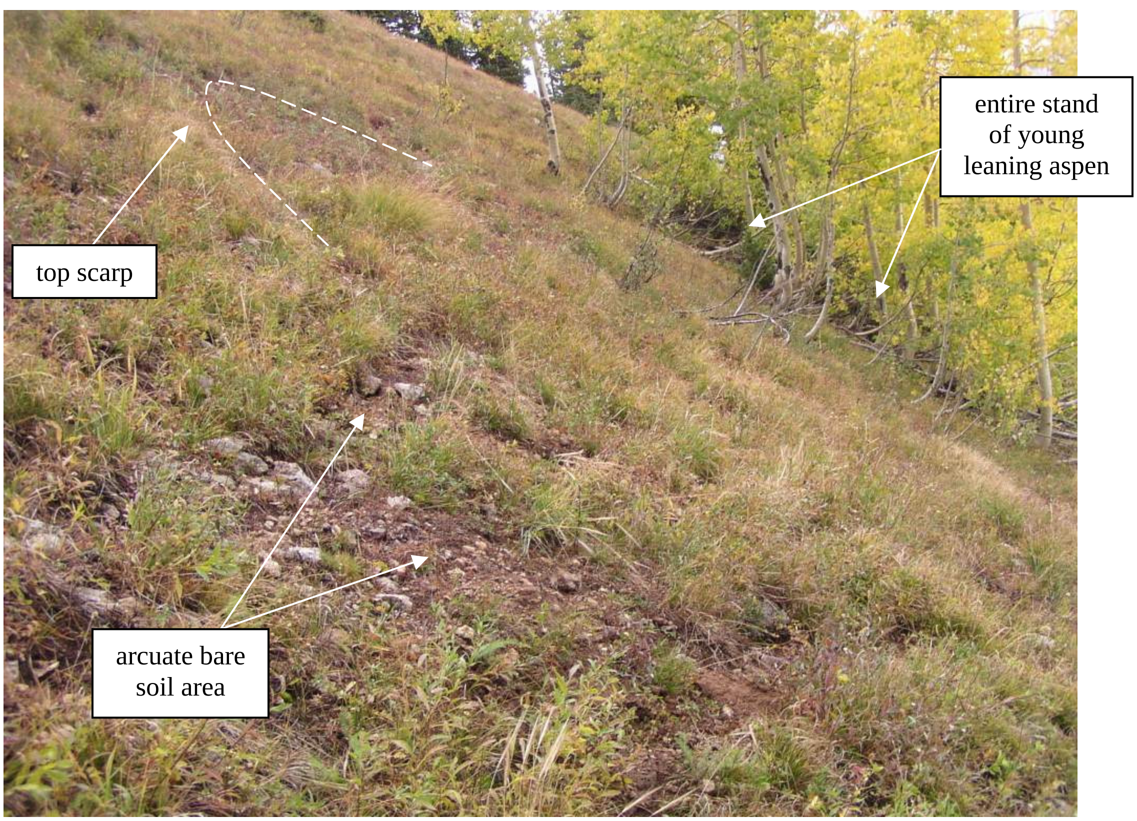
The East Facet (GHU #7) is a roughly triangular-shaped area located west and upslope from the Chicken Bone (GHU #6) and northeast and upslope of the Upper Narrows (GHU #8) (see Overview Photograph on page 13 and Maps 2 and 2B). There are 8 ground photographs of the East Facet presented in Appendix C as photos FC01 to FC08. See Map 5 (Appendix A) for locations and orientations of these photographs.

The ground surface of the East Facet forms a concave bowl that slopes generally at grades of 30-50% down to the east with steeper slopes, greater than 80%, below the upper rim and at other locations on the lower slopes. The forest cover generally consists of thick stands of conifers with some areas of sparse conifers and scattered aspen patches. The surface soils are permeable, derived mostly from weathered igneous intrusive rock, and there is little or no development of drainage channels. In the open areas, the groundcover includes grasses and small shrubs with many areas that are poorly vegetated with exposed mineral soil. The road to the top of Snodgrass Mountain traverses the lower slopes of the East Facet and, at one location (el. 10,490'), appears to have been repaired subsequent to movement of a small fill slope landslide.

The conifer tree cover on the upper slopes is older than on the lower slopes and contains numerous dead standing snags. The contact between the forest canopy's textures, when observed from below, is a series of gentle arcs that are concave upslope, as seen in the following photograph. This suggests possible movement of the slopes, which would displace whole clusters of trees, but this has not been verified on the ground.



Several small aspen stands on the northeast portion of the area are on clearly identifiable small slumps and the small size of the leaning aspen indicates slope movement within the last 25 to 50 years. Also, within an area of sparse conifers a top scarp was clearly identifiable, as shown in the following photograph, near the middle of the East Facet at an elevation of 10,575 feet. The leaning and bent trees on the slide mass suggest ground movement within the past 100 years.

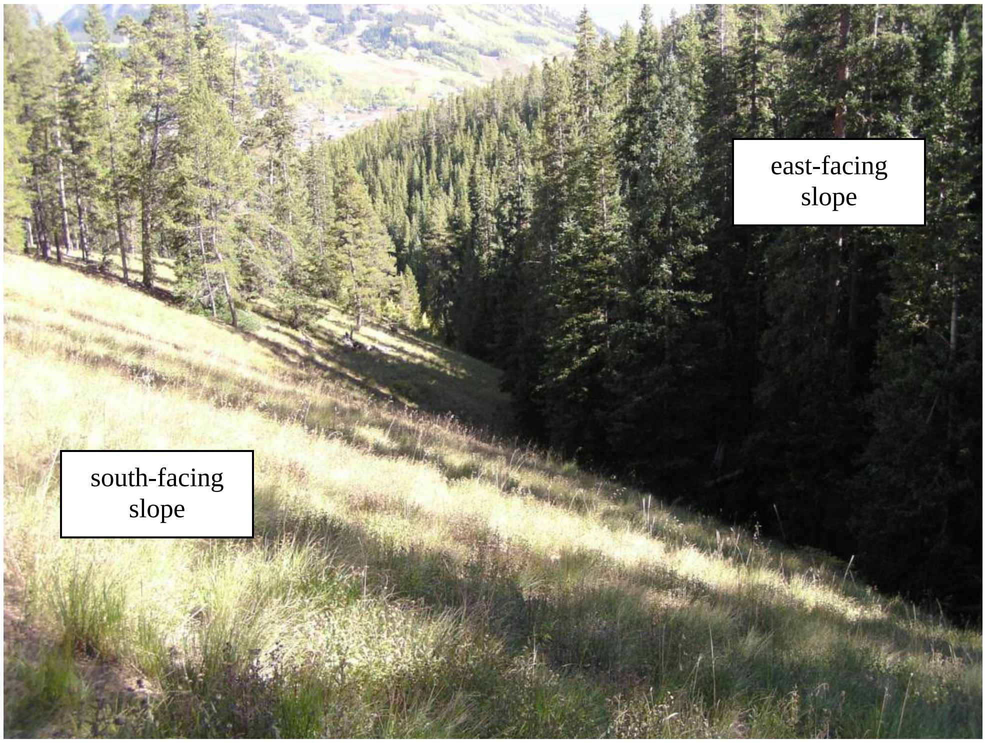


The East Facet has similar aspect, slope, morphologic shape and geology to the Upper West Slide (GHU #1, also known as the West Facet). The bowl surface, in both cases, appear to have been formed by large old landslides. The steep slopes below the western ridge of both units are arcuate in plan view and lie above flatter areas. Based on the study of aerial photographs and the 5-foot contour topographic map, these appear to be scarps and slump blocks, but the scarps were not observed in the field. It is likely that the intrusive igneous rock of the Snodgrass Laccolith failed with gradual loss of strength of the underlying, weaker shale. Based on the mature forest that is present, it has probably been at least 100 years since the last large movement.

8. Upper Narrows – GHU #8

The Upper Narrows (GHU #8) contains the Unnamed Drainage and is separated from the East Facet (GHU #7) by a sloping ridge and it is directly below the Upper Bowl (GHU #9) in the upper portion of the mountain (see Overview Photograph on page 13 and Maps 2 and 2B). There are 16 ground photographs of the Upper Narrows presented in Appendix C as photos UN01 to UN16. See Map 5 (Appendix A) for locations and orientations of these photographs.

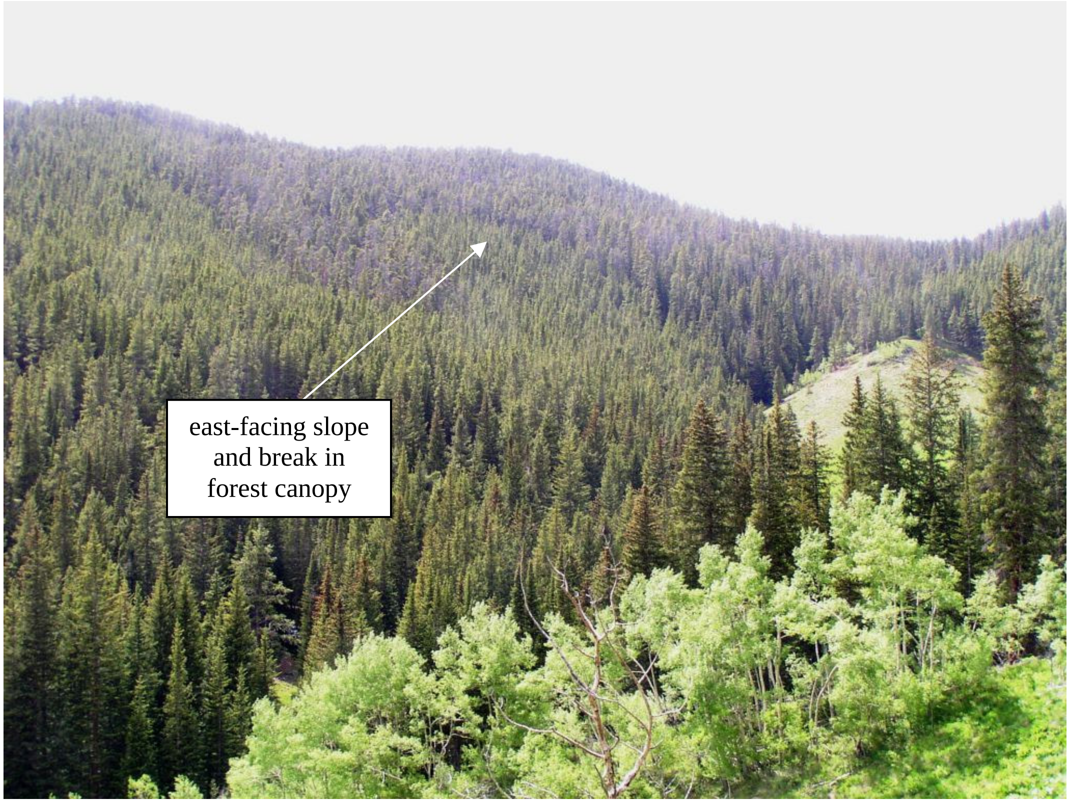
The dirt access road that accesses the top of Snodgrass Mountain crosses the upper, northern portion of the Upper Narrows. On the northeast side of the Unnamed Drainage, the slope faces south and varies from 35 to 45%. This south-facing slope is heavily wooded with conifers above the road and patchy stands of conifers amongst sloping meadows below the road. On the southwest side of the Unnamed Drainage, the slope faces east to northeast, is densely wooded with conifers, and slopes generally varies from 35 to 60%. The following photograph, taken looking down the Unnamed Drainage, shows the densely wooded east-facing slope on the right and the more open south-facing slope (below the road) on the left.



The surface soils of the Upper Narrows are granular and permeable and there were no established channels observed during field inspections. Fractured igneous intrusive bedrock outcrops on the lower half of the sloping ridge that separates the Upper Narrows from the East Facet (GHU#7). It is likely that the ground slope parallels the dip of the upper surface of fractured igneous intrusive rock, which is down to the west towards the Unnamed Drainage. The aforementioned access road crosses this slope and shows evidence of a previous slide lowering the grade of the road (el. 10,565'). Additional evidence of the slide is supplied by the numerous leaning and trees bent upslope. A traverse of the slope above the road (June 24, 2005, including M. Burke, J. McCalpin, T. Hughes and J. Almy) revealed no cracks in the ground or topographic expression of scarps. However, inspection of the project topographic map (5-foot contours), aerial photographs and orthophotos, reveals arcuate patterns in the ground consistent with slope failure. Most of the trees on the south-facing slope were straight but many of the ones that were not, had bends at about 20 feet below the top, indicating movement at about the same time perhaps 20 years ago (assuming a rate of growth of 1-foot per year). Some earthflow deposits were observed infringing on the Unnamed Drainage at the base of the south-facing slope, within the Upper Narrows. The slope above one of these lobed areas was observed to have numerous leaning trees.

Geologic mapping by Gaskill (1991) showed bedrock in this portion of the mountain to be igneous intrusive rock and, although not field checked for this report, the surface soils are probably also granular and permeable. According to the *Taylor River Soil Survey* (NRCS and USFS, in progress), the soils in this area are mapped as loamy skeletal, which confirms its granular and well-drained nature. Other than the Unnamed Drainage, no established channels were identified on aerial photographs on either side of the main drainage channel. On the southwest side of the valley, the slope of the ground surface is transverse to the dip of the igneous-shale contact. The pattern of 5-foot contour lines suggests at least one slump on the lower slope just above the Unnamed Drainage in the narrow portion of its valley (el. 10,465').

As with the East Facet (GHU #7), there are some locations with a change in the texture of the tree canopy that can be seen as arcs that are concave upslope. The forest below the arcs appears to be younger and there are fewer dead and leaning trees compared to above the arcs. Further ground investigation is suggested to observe whether scarps or topographic breaks exist in this area to determine whether this forest change indicates previous slope movement. The following photograph, taken looking up the Unnamed Drainage, shows the texture of the dense forest on the east-facing slope of the Upper Narrows.



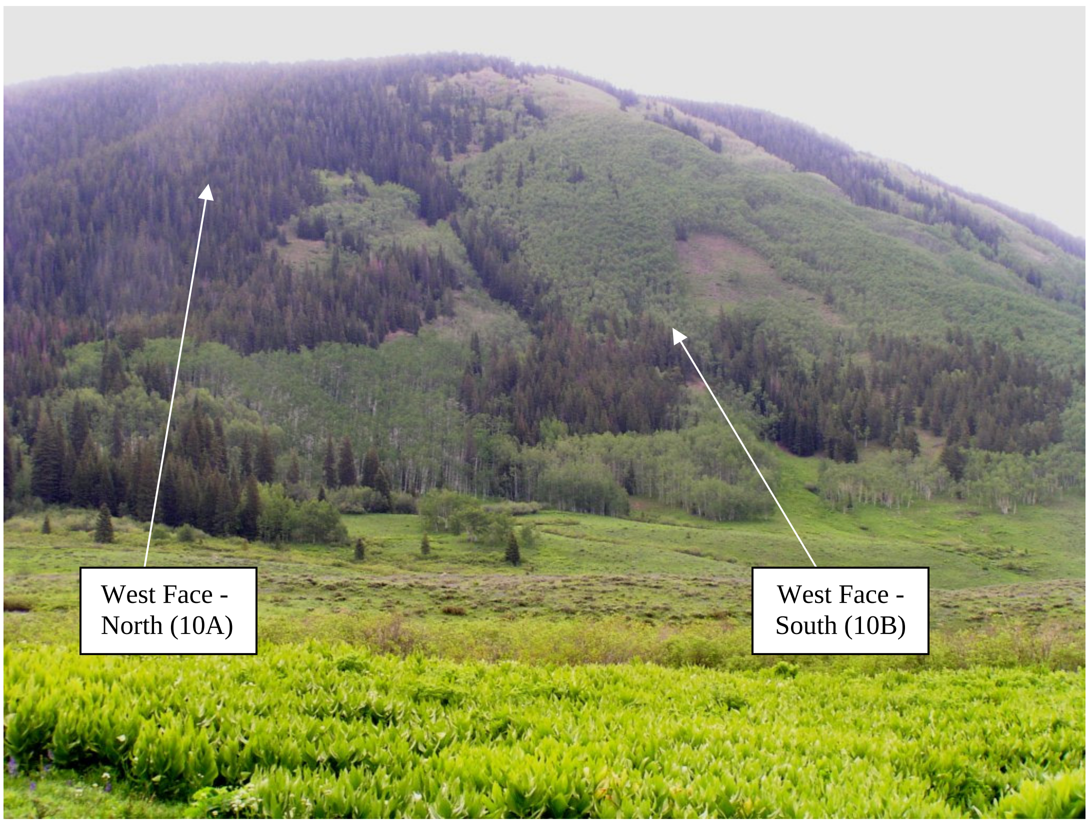
9. Upper Bowl – GHU #9

The Upper Bowl (GHU #9) is the upper part of the southeast side of Snodgrass Mountain (seen at the top of the Overview Photograph on page 13). No ground photographs are available of the Upper Bowl. This is the basin from which the Unnamed Drainage originates and it is defined by two southeast-trending, sloping ridges that descend from the summit. The slopes are gentle and are generally under 25%, with small areas with slopes of up to 40%. The aspect ranges from southwest to northeast and it is densely wooded with conifers. Surface soils are granular and permeable and bedrock is igneous intrusive rock of the domed top of the Snodgrass Laccolith. According to the *Taylor River Soil Survey* (NRCS and USFS, in progress), the soils in this area (and other areas in the upper mountain) are mapped as loamy skeletal, which confirms its granular and well-drained nature. No evidence of slope instability was observed in the Upper Bowl. However, it cannot be ruled out on some of the short, steeper slopes.

10. West Face (North and South) – GHU #10A and #10B

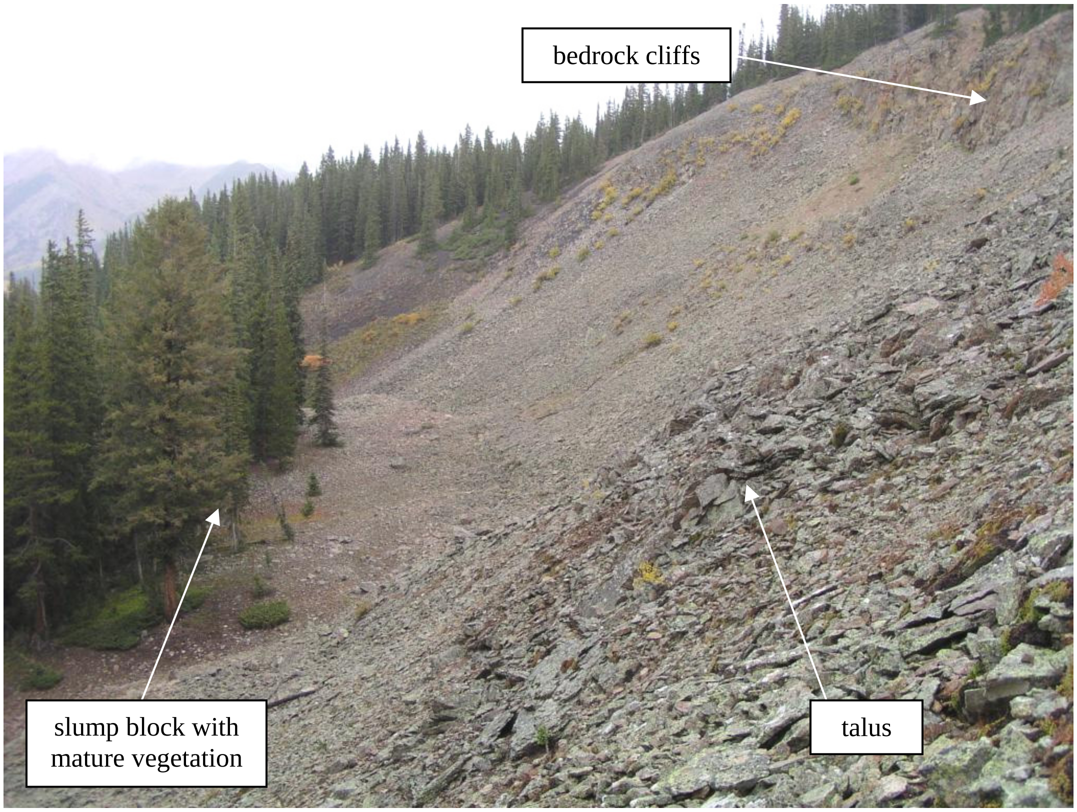
The West Face (GHU #10) faces west and northwest and extends from the summit of Snodgrass Mountain (el. 11,125 feet) down to the Washington Gulch valley. This unit was further subdivided into a larger, northern component (GHU #10A) that extends from the summit to the valley floor and a smaller, southern component (GHU #10B) that covers the lower portion of the mountain along the southern edge of the proposed ski area boundary (see photograph on the following page and Maps 2 and 2C). There are 20 ground photographs of the West Face presented in Appendix C as photos WF01 to WF20. See Map 5 (Appendix A) for locations and orientations of these photographs.

The slopes of the West Face are generally moderately steep to steep throughout this unit. The vegetation consists of predominately conifers on most of the West Face – North unit, with mixed aspen and conifers on the lower slopes. The West Face – South unit is vegetated with aspen in the upper portion and a mixture of aspen and conifers in the lower half. Some areas have only grasses and shrubs. The following photograph, taken looking roughly southeast at the western side of Snodgrass Mountain, shows the character of the West Face. A portion of the North Face (GHU #11) is seen on the left side of the following photograph as the steep slope with a dense cover of conifers.



On the West Face – North unit, the upper two-third's of the area contains soils that are thin and granular, developed in-place from weathering of the underlying fractured igneous intrusive rock of the laccolith. Where exposed, the igneous rock is fractured and jointed. At mid-elevation in this unit, there is a band of terrain that exceeds grades of 40% and, is often much steeper, including near vertical bedrock cliffs. These areas are old block slumps in igneous intrusive rocks, indicated by bare talus deposits below bedrock cliffs. These rock slumps have likely developed along the contact of the igneous rock with the underlying Mancos Shale and are due to weakening of shale underlying fractured igneous intrusive bedrock. These areas also have rockfall potential. The following photograph, taken of the largest area of exposed bedrock cliffs and talus, shows the nature and steepness of this landform, located in the northern portion of the

West Face – North unit (el. 10,400). This area, and a smaller similar outcrop, show up clearly on the orthophotos, topographic map, and is easily viewed from Washington Gulch Road.



The mature conifers on the slump block in the above photograph indicate that major movement is probably older than 100 years. However, curved traces are visible on the orthophoto just upslope from the main scarp, suggesting that retrogressive failure up the slope is developing.

On the upper slopes of the West Face – North unit, there are areas with leaning and bent mature conifers and topographic patterns that suggest older slumping or translational sliding probably longer than 100 years ago. These are especially noticeable on the topographic map along the northeast edge of the West Face where it adjoins the North Face. In that area, there is a series of six topographic benches and obvious uneven topography. In the lower portion of the this unit, where the vegetation consists of mixed conifers and aspen, soil creep is common. In this zone, shallow translational landslides, in the soil and near-surface fractured rock, were observed to transition into earthflows.

On the West Face – South unit, there are a number of types of mass wasting, including soil slumps, accelerated creep, and shallow translational slides that transition into earthflows. The soil composition in this unit varies and consists of mudflow and earthflow deposits, as well as glacial deposits. Accelerated creep is common in this unit, particularly in clearings and aspen stands. This type of creep is indicated by soil cracks, linear and arcuate bare soil patches, and leaning trees. The freshness of the cracks and lack of vegetation indicate very recent soil movement, probably within the past few years. Several soil slumps, within earthflow deposits on the lower part of the mountain, exhibit fresh unvegetated scarps and are probably less than 10 years old. One such small slump is shown in the following photograph. Notice the bare soil in the scarp, the disrupted vegetative pattern of the groundcover, and the many young aspen trees in the background that are leaning in various directions.

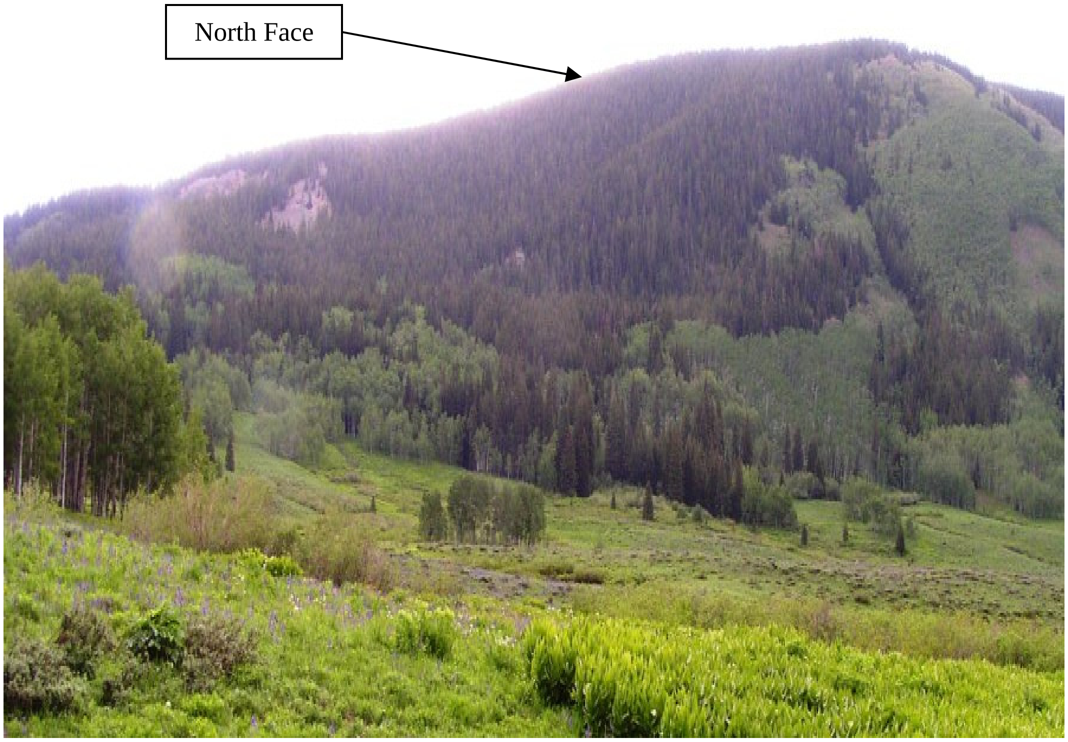
On the lower slope, near the southern edge of the West Face - South unit, there is a translational slide with a circular (in plan view) main scarp that transitions into an earthflow. Except for clumps of grasses and a small stand of young aspen, there is very little vegetation on the exposed failure surface. This arcuate area is clearly seen in the photograph on page 32, to the right of the right arrow. The main scarp at the top of the evacuated area is only a few feet high and exposes fractured igneous intrusive rock. The earthflow deposition zone is currently or very recently moving, as evidenced by large exposures of bare mineral soil, the leaning and bent young aspen trees, cracks in the ground, and displacement of a barbed wire fence (see following photograph). The mottled appearance of the aspen canopy and arcuate traces on aerial and orthophotos, suggest that upslope and laterally to the south of this area, accelerated creep is occurring and slumps are starting to develop. The following photograph, taken of this earthflow, shows the exposed soil, leaning trees, and fence posts that are being dragged and pulled to the ground.

Just north of the earthflow deposition zone described above, there is an earthflow path that probably formed within the past 100 years based on size and estimated age of medium-sized aspen and small conifers (el. 9,825'). Further to the north, there is a larger area of earthflows with widespread accelerated creep in and upslope from the starting zones.

11. North Face – GHU #11

The North Face (GHU #11) extends from the summit of Snodgrass Mountain down to the north and northeast. As seen on Maps 2 and 2C, the North Face is bordered on the west by the West Face (GHU #10), on the south by the Upper Bowl (GHU #9) and the East Facet (GHU #7), and on the east by the East Face (GHU #12). There are 3 ground photographs of the North Face presented in Appendix C as photos NF01 to NF03. See Map 5 (Appendix A) for locations and orientations of these photographs.

The following photograph, taken from near the valley floor of Washington Gulch looking east-southeast, shows the ridge between the West Face – North and the North Face. The North Face is actually beyond the ridge to the east and it has a northeast aspect. Some areas of the North Face are heavily wooded, while other areas have patchy tree cover, grassy meadows, and bare rock chutes.



The upper slope of the North Face (GHU #11) is formed from fractured igneous rock with little or no residual soil cover. This steep, rocky, open slope is shown in the following photograph.

Numerous debris and rock slides have occurred on the steep upper slopes, starting in the weathered and jointed igneous rock. These slide zones can be seen on Map 2 as narrow rocky (unvegetated), parallel chutes that run, perpendicular to the contours, from near the summit of Snodgrass down to Gothic Road and below. These rock slides, as well as snow avalanches, have removed or prevented tree cover from becoming established due to regular events.

12. East Face – GHU #12

The East Face (GHU #12) is located east of the North Face (GHU #11) and the East Facet (GHU #7), on the north and east side of the ridge that separates it from Chicken Bone (GHU #6), Middle Slide Complex (GHU #3), and East Slide Complex (GHU #5). Because it is located on the more northern and eastern side of the mountain, it is only partially seen on the Overview Photograph (page 13), but it is clearly identified on Maps 2 and 2B. There are 14 ground photographs of the East Face presented in Appendix C as photos EF01 to EF14. See Map 5 (Appendix A) for locations and orientations of these photographs.

The East Face was referred to in the Irish (1996) report as the "Lateral Moraine Ridge" area and also includes a portion of the more gently-sloping "East Slope" area. A large landslide complex is mapped by Soule (1976) in this unit and it extends from within this unit down to below Gothic Road. This area was not analyzed by M. Burke as most of it is outside of the proposed ski area boundary. However, at least half of the mapped landslide is within the USFS boundary. Aerial photographs and orthophotos suggest that there are numerous landslides to the north of the switchback, but these areas were not studied in detail. Therefore, their age and relative stability are not known.

The East Face is located at the base of the East Facet and northeast of the Chicken Bone, where the slopes are relatively gentle (15-30%). The hummocky ground surface, patchy conifer forest cover, and soils are similar to the Chicken Bone unit and probably were formed by the same large landslide originating on the East Facet. The East Face has extensive large rock slumps that developed in the shale bedrock and they are visible on aerial and orthophotos. There are also smaller slumps that have transitioned into earthflows. The terrain is also clearly hummocky on the topographic map. Both the slumps and earthflows have partially covered glacial moraine soils on the topographic bench at the base of the slopes proposed for development.

Below the area geologically and topographically similar to the Chicken Bone, the slopes are steeper (30-60%), and the study of aerial photos as well as field checking revealed a number of landslides that appear to have been active within the past 100 years. There are a number of slides that the access road traverses in the depositional area below the East Facet (GHU #7). The following photograph was taken of the lateral scarp of one such slide. Note the change in aspect of the ground surface, the dip in the road where the car is located, and the leaning and bent trees. The head of the scarp is upslope of the road and an arcuate scarp and slump block are obvious features in that area. More slumps were observed along the road uphill of this site.

The supporting evidence for the interpretation of these areas as slump blocks includes the sparsely vegetated soil, disruption of trees, shape of the ground surface, and review of the detailed topographic map. Aerial photograph interpretation supports these a being landslides, and the leaning and bent trees visible on the ground, support a likely age of under 100 years since last movement. Additionally, just south of where the access road reaches the ridge between the Chicken Bone (GHU #6) and the East Slide Complex (GHU#5), there is a sag pond at the head of a slide, which extends to below the lower road (el. 10,250'). The middle portion of this slide has numerous leaning and bent aspen suggesting movement within the last 25 to 50 years. A several hundred foot long portion of the lower road appears to have been displaced by movement of a landslide (el. 10,000'). The amount of displacement is minor, but probably occurred within the past 100 years.

There is a slide or series of slides that extends from the top of the East Face, just north of the main scarp of the East Slide Complex (GHU #5), across the road, and down to the flatter slopes at the bottom of the East Face. The following photograph was taken of the stand of aspen being moved by the slide. Note the extensive area of leaning and bent trees that extend up the slope, suggesting movement within the last 25 to 50 years. Some trees are leaning uphill, some downhill, and others are bent mid-trunk.

13. Unverified Areas – GHU #13

The Unverified Areas Geologic Hazard Unit (GHU #13) was selected to represent the small areas along the southern edge of the USFS boundary that are outside of the areas studied in detail on the ground. This was due to their topographic positions on the south sides of ridges and very limited area due to the property boundary, so they would likely be outside of a ski area (see Map 2). They would be considered impractical as potential ski runs due to their poor accessibility and limited extent. The two areas of USFS property that fall into this category are located south of GHU's #9, 10.A. and 10.B. and south of GHU's #1.A. and 8. No attempt was made to identify their specific geologic setting or to place an Age Class for slope movement (Table 1). However, based on aerial photograph analysis, a slope stability class was assigned to these areas based on similar geomorphic characteristics observed on adjacent GHU's (Table 2) in order to complete the mapping of USFS property on Snodgrass Mountain. Also, due to the low probability of development of these inaccessible areas, no assessment of risk for slope movement due to ski are development was performed. If these small areas are to be further considered for development, they would need to be studied in the field for evidence of slope movement.

C. Ages and Relationships of Landslides

In summary, most of the GHU's evaluated, except for the Upper Bowl (GHU #9), were determined to have at least some amount of slope movement within the past 100 years (McCalpin Age Class 1) to past 5,000 years (Age Class 2). Table 1 (page 14) and Table 2 (below) show a summary of the estimated age of the youngest slope movement observed or interpreted within any part of a GHU, without reference to the percentage of the GHU that exhibits that age of movement or where those areas of young movement are located within the GHU polygon. It is important to emphasize that the Age Class in Tables 1 and 2 represent the most active features of the GHU and may not be representative of the entire unit. For example, the Upper West Slide (GHU #1A) is identified as having both Age Class 1 and Class 2 features, but the entire Upper West Slide may not be active or moving as a recent unit. In effect, many GHU's that have been assigned Age Classes 1 and 2 in Tables 1 and 2, may actually contain only small areas of movement that are young, with the majority of the GHU composed of slopes exhibiting older movement or even stable areas where there is no evidence of slope movement. However, this was done to identify that there are unstable or marginally stable slope conditions within a GHU that deserve consideration and possible mitigation before development can occur.

To best summarize and illustrate the current state of slope stability on Snodgrass Mountain based on this USFS study of GHU's, Slope Stability Classes were assigned to each GHU and presented in tabular form (Table 2) and on a map (Map 3). The following Table 2 summarizes the categories of slope stability and supplements Map 3 with a key to the color-coding on the map.

Table 2. Slope Stability Classes for Each Geologic Hazard Unit (GHU's) – Current State of Snodgrass Mountain

# of GHU	Name of GHU	Age Class*	*Slope Stability Class***
1 A	Upper West Slide	1-2	**US**
1 B	Lower West Slide	1	**LS**
2	Slump Block	1	**LS**
3	Middle Slide Complex	1-2	**US**
4	Lower Earthflow	1-2	**LS**
5 A	Upper East Slide	1-2	**US**
5 B	Lower East Slide	1	**LS**
6	Chicken Bone	1-2	**SS**
7	East Facet	2 (locally 1)	**PUS**
8	Upper Narrows	1-2	**PUS**
9	Upper Bowl	3-4	**SS**
10 A	West Face - North	2-3	**PUS**
10 B	West Face - South	1-2	**US**
11	North Face	1-3	**PUS**
12	East Face	1-2	**PUS**
13	Unverified Areas	1-4	**PUS**

*See Table 1 for range of years assigned to the Age Classes.

** SS = Stable Slope PUS = Potentially Unstable Slope US = Unstable Slope LS = Landslide

As is no surprise to those familiar with the mountain, the area of greatest concern for slope stability because of the features observed and described in the previous section, is the lower southeast slope of the mountain, as was also concluded by several previous studies (RCE, 1995; Irish, 1996; Baum, 1996). However, this USFS study suggests that there are other areas of Snodgrass Mountain have geomorphic features that deserve attention, as well.

Map 3 and Table 2 have four levels of slope stability: Stable Slopes, Potentially Unstable Slopes, Unstable Slopes, and Landslides. The definitions of these terms are consistent with those used by Soule (1976) in his mapping of the geologic hazards of the region, the Colorado House Bill 1041, and the Colorado Geological Survey's *Guidelines and Criteria for Identification and Land Use Controls in Geologic Hazards and Mineral Resource Areas* (Rogers et al., 1974). A summary of these definitions is as follows:

- "Stable Slope" – This is a slope that may have moved in the past, but current evidence suggests the movement is very old and it is not currently active.
- "Potentially Unstable Slope" – This is a slope that "contains attributes of an unstable slope, but past or present failure is not apparent." The "attributes" of an unstable slope may be "composition of surficial and bedrock materials, proximity and geological similarity to slopes that have failed in the past of are failing now, slope angle and aspect, soil moisture conditions, and microclimate."
- "Unstable Slope" – This is a slope "with landslide-earthflow physiography, but where modern slope movement is not apparent or is uncertain, [and] such areas have undergone slope movement in the recent geologic past (late Pleistocene-Holocene)."
- "Landslide" – This is an "area with demonstrably active natural movement of landslides or earthflows…evidence for modern slope movement(s) includes distinctive physiography and disrupted vegetation or structures."

As seen in Table 2 and Map 3, the four Geologic Hazard Units in the lower southeast portion of Snodgrass Mountain are classified as "Landslides." This includes the Lower West Slide (GHU #1B), Slump Block (GHU #2), Lower Earthflow (GHU #4), and Lower East Slide (GHU #5B). The four GHU's classified as Unstable Slopes are the Upper West Slide (GHU #1A), Middle Slide Complex (GHU #3), Upper East Slide (GHU #5A), and West Face – South (GHU #10B). The six Potentially Unstable Slopes are the East Facet (GHU #7), Upper Narrows (GHU #8), West Face - North (GHU #10A), North Face (GHU #11), East Face (GHU #12), and Unverified Areas (GHU #13). The two GHU's classified as Stable Slopes are Chicken Bone (GHU #6) and Upper Bowl (GHU #9).

Regarding the relative ages of movement in the lower portion of the southeast slope, including the West Slide Complex (GHU #1), Slump Block (GHU #2), Middle Slide Complex (GHU#3), Lower Earthflow (GHU #4), and East Slide Complex (GHU #5), previous investigators disagreed about the sequence of landslide movement. For example, RCE (1995) believed that the East Slide moved before the West Slide, while Irish (1996) and Baum (1996), believed the opposite. RCE considered Baum's Slump Block to be part of the West Slide Complex. Irish considered it to be in-place shale. Baum placed movement of the Slump Block earlier than movement of the West Slide Complex. Based on field observations and the study of aerial photos, M. Burke believes that the West Slide Complex moved first towards the southeast and that the Slump Block was formed by a subsequent large landslide that developed in the toe of the

Lower West Slide. The main scarp upslope from the Slump Block appears to curve uniformly, except where interrupted by scarps or covered by earthflow deposition. Its form appears too uniform to have been modified by massive movement of the West Slide Complex. The slumps on the south-facing slopes in the upper part of the Middle Slide Complex developed in the steep lateral scarp of the West Slide Complex.

The zone of accumulation for the East Slide Complex covers part of the Slump Block, so it had to have occurred later and is, therefore, younger. Previous investigators believed that the Slump Block buttressed the Lower West Slide and reduced the chance of additional movement. However, it is apparent that movement of the Slump Block created a steep high scarp in shale which destabilized landslide deposits on the slopes above it, and set forth the necessary conditions for development of the East Slide Complex and the lower fresh scarps of the Middle Slide Complex. The slopes on the scarp at the base of the Lower West Slide are generally steeper than 40%, which is typically too steep for long-term stability in Mancos Shale.

VI. POTENTIAL EFFECTS OF SKI AREA DEVELOPMENT ON SLOPE STABILITY

The previous section of this report identified sixteen GHU's on Snodgrass Mountain having similar characteristics, discussed the nature of past movement, and presented a map showing the potential for slope movement in the mountain's current state. The following section evaluates the various ski area activities and their possible impacts on slope stability for each GHU and introduces some options for mitigation. In addition, the probability of inducing slope movement by a ski area activity and the severity of this impact are assessed. This information is summarized in Tables 3A through 3F (Appendix B). By necessity, the risk of instability within each unit is given a generalized rating that represents the average impact of a ski area activity on the sensitive slopes within that unit. Both the potential for slope movement and the severity of impact were assessed for Snodgrass Mountain in its current state, without benefit of mitigation. However, mountain-wide mitigation measures are offered. Additional mitigation measures are suggested, for consideration in reducing the impacts in the more sensitive portions of each of the GHU's. Detailed mitigation cannot be prescribed until the site-specific aspects of the various activities are identified and quantified.

A. Mountain-Wide Mitigation Considerations

The purpose of mitigation is to reduce the slope stability hazard potential and to minimize environmental affects posed by ski area development on Snodgrass Mountain. However, it is worth stating that "it is not possible, feasible, or even necessarily desirable to prevent all slope movements. Furthermore, it may not be economically feasible to undertake physical modifications in some landslide areas" (Wold and Jochim: 1989). Also, as previously discussed, most beginner and intermediate ski slopes in Colorado are on postglacial landslide deposits that lie on the lower flanks of steep mountains (McCalpin, 2005). The challenge is, therefore, how to design and operate a ski area on landslide terrain without loss of life, degradation of natural resources on National Forest System lands, or damaging ski area infrastructure. As stated in the RCE (1995) report, there are four standard design approaches for mitigation that should be considered for development on landslide or unstable slope conditions:

1. Avoidance of problematic areas.

2. Eliminate/stabilize unstable areas with removal and recompaction.

3. Reduce the load that creates the instability by grading.

4. Increase the strength of the resisting forces with improved drainage and earthen buttresses.

The most effective way to increase the strength of the resisting forces is to control surface water infiltration and remove water in the subsoils. Controlling drainage of both natural sources of water (rain and snowmelt) and man-produced water through snowmaking operations will be especially important on these slopes to preserve slope stability.

Geologic hazard risk depends on the selection and effectiveness of mitigation measures, both in principle and in application. For example, an excavation into the toe of a landslide or potentially unstable slope to reduce the side hill on a ski trail can be made stable if the slope is mechanically reinforced. Such stabilization requires sophisticated design, may not provide a guarantee of complete stabilization, can be expensive, and may not be a feasible option for a ski area. Also, mechanical slope stabilization can be visually intrusive on the environment, which may not be desirable to the proponent or the public. In some cases, effective mitigation is possible but not practically attainable and some risk of slope failure may remain. The selection of mitigation measures for the project depends on the degree of risk and level of potential damage to the resource and infrastructure that are acceptable to the USFS and the project proponent.

The following considerations should be made when evaluating ski area activities on slopes with potential instabilities on Snodgrass Mountain. The measures are recommended as concepts to be considered for "mountain-wide" mitigation for all ski area activities:

1. Avoid placing all structures, roads, buried utilities, and lift terminals on active (Age Class 1) landslides.

2. When avoidance is not possible, design and construct all improvements on landslides to preserve or increase overall slope stability. See "Typical Mitigation Measures" for each ski area activity as possible ways to improve the stability of slopes.

3. Aggressive surface and subsurface drainage features should be installed to capture and remove water from sensitive slopes. This would entail development of fully integrated, mountain-wide grading, transportation, utility, and drainage plans.

As discussed by McCalpin (2005), the compatibility of ski area development with slope movement should be evaluated with human safety as the primary factor, resource damage as the secondary factor, and infrastructure damage as the tertiary factor. According to McCalpin, the hazards posed by landslides are a function of landslide velocity and probability of occurrence of the various types of landslides. Mitigation of these hazards is intended to reduce the probability of occurrence of landslides and to make the landforms more compatible with ski area activities.

B. Ski Area Modifications/Activities

The development of Snodgrass Mountain for alpine skiing would include grading and slope shaping for the construction of some ski trails, clearing of trees and tall shrubs, snowmaking, trenching for buried utilities and installation of other infrastructure (power, water, sewer, communications), construction of access roads, and erection of structures such as liftline towers, terminals and buildings. All of these activities involve disturbance of the existing conditions and modifications to the slopes. Therefore, an understanding of the severity of these impacts on different areas of Snodgrass Mountain is very important. Although it is understood that CBMR will keep the clearing, grading and number of liftlines to a minimum, the total elimination of any of the above disturbances is not likely. Also, snowmaking is likely necessary due to the mountain's elevation and aspect of the proposed slopes. Therefore, the potential effects on slope stability of each potential activity will be considered below.

Most ski area activities potentially impact natural drainage patterns. Although drainage controls are not a direct ski area modification, they are a critical component of all of the construction and maintenance activities of the ski area in order to preserve slope stability. Consequently, a mountain-wide drainage plan must be developed that integrates grading, clearing, road and utility construction, structures, and snowmaking, yet protects the many wetlands that occur on the mid and lower portions of the mountain. Great care must be taken to control runoff, reduce erosion, and prevent saturation of unstable and potentially unstable slopes.

For each of the six main ski area activities to be employed on Snodgrass Mountain (grading and slope shaping, clearing, snowmaking, buried utilities, roads, and liftlines/structures), there are three discussions for each activity in the following sections:

1. The general effects or potential impacts of these activities on slope stability;
2. The typical mitigation measures employed to reduce the impacts of these activities; and
3. The potential effects of each ski area activity on the stability of the GHU's.

The potential effects of the six ski area activities on slope stability are presented in detail for each GHU in Tables 3A through 3F (Appendix B). It should be emphasized that the text below provides selected examples of these potential effects to supplement the corresponding tables, but they are not meant as exhaustive explanations for all GHU's.

1. GRADING AND SLOPE SHAPING

a. General Effects of Grading and Slope Shaping on Slope Stability

The shaping of steep portions of a landslide to produce slopes that are more suitable for skiing can enhance slope stability, if properly designed. This is done by reducing patterns of loading that tend to push unstable slopes downhill and by adding soil and rock to areas that buttress or resist slope movement. However, if the dynamics of the landslide are not understood, shaping and grading can be detrimental to slope stability. Grading removes or buries the root mass of all species of vegetation. Also, through redistribution of weight on slopes, grading may decrease or increase stability. Generally, removing weight from the toe or lower portion of a landslide and adding weight to the crest or upper portion of a landslide will decrease its stability. Conversely, the stability of a slope can be improved by either adding weight to the toe of a landslide to effectively buttress the slope or by removing weight from the upper region of a landslide to unload it. For deep slides such as earthflows, construction of roads or ski trails across the middle slopes that balance cuts and fills may not change the stability. However, for shallow slides or potentially unstable slopes, any cutting could destabilize the slopes above, and any fill could destabilize the slopes below. For complex slides that have a series of slump blocks and scarps extending up the hill (retrogressive failure), flattening the scarps will place additional weight on the slump block below and reduce its stability. It also will reduce mass buttressing of uphill slopes.

If grading increases the efficiency of the surface drainage network it may increase slope stability. On the other hand, infiltration may be greater in loosely placed fill than on a previously undisturbed slope or scarps with little soil development, and stability could decrease through increased water infiltration and saturation of the subsoils. Rapid removal of runoff and meltwater from sensitive slope areas is essential.

b. Typical Mitigation Measures for Grading and Slope Shaping

Grading and slope shaping for creating ski trails often involve cuts and fills to achieve intended slope angles. Cuts and fills are typically used for constructing access roads on sloping terrain within a ski area. Therefore, the following discussion is also applicable to the development of roads (Section VI.B.5.b). Depending on the GHU, cuts and fills could traverse a variety of landforms such as landslides and slumps (of various ages), bedrock outcrops (hard igneous intrusive rocks and soft, weathered shale), slopes containing colluvium and glacial debris, etc. The different landforms would require different mitigation methods. It is anticipated, based on construction practices used in the area, that most deep cuts in shale-derived soils may require mechanical stabilization, such as soil nails or tie-backs. Likewise, dewatering, diversion of surface drainage, and reinforced earth fills may be required for shaping some colluvial and alluvial slopes. The Colorado Geological Survey (Wold and Jochim, 1989 and Rogers et al., 1974) has provided a list and discussion of physical mitigation methods for various geologic hazards such as slides and slumps, debris flows, and rockfalls. These methods, combined with other methods used for preserving slope stability when modifying the shape of the terrain, are provided below.

Drainage

a. Surface drainage
    1. lined or unlined drain ditches
    2. regrading/berming
    3. surface sealing – polymer products
b. Subsurface drainage
    1. horizontal drains
    2. vertical drains/wells
    3. French drains/intercept drains
    4. cut-off drains/counterforts
    5. drainage galleries or tunnels
    6. blanket drains

Excavation across a landslide surface

a. excavation to unload the upper portion of the landslide
b. add artificial or native material to the toe of the landslide to buttress slope (rock- or earth-fill buttressing)
c. bridging weak or moving zones
d. removal of unstable material (unless at toe of slope)
e. avoid loading on unstable surfaces

Fill slope retaining structures

a. retaining walls – Hilfiker walls, gabions, deadman timber walls, cribbing, geogrid, reinforced earth walls
b. light weight artificial fill material
c. driven piles, drilled micropiles
d. buttresses and counterweight fills
e. tieback rods and anchors
f. rock bolts/anchors/dowels

Cut slope retaining structures

a. retaining walls - Hilfiker walls, gabions, boulder stack, deadman timber walls
b. driven piles, drilled micropiles
c. buttresses and counterweight fills
d. mechanical stabilization – tie-back rods, soil nails and anchors
e. rock bolts/anchors/dowels
f. wire mesh and shotcrete

Stabilization of exposed bedrock uphill of graded slopes

a. excavation, scaling, trimming
b. benching
c. rock bolts/anchors/dowels
d. chains and cables
e. anchored mesh nets or fencing
f. shotcrete/gunite application (cementing)
g. buttresses

Protection from exposed bedrock uphill of graded slopes (rockfall)

a. rock trap ditches
b. catch nets and fences
c. catch walls
d. rock sheds or tunnels

Re-vegetation

a. hydro-seeding
b. mulching
c. fertilizing
d. use of native trees and shrubs (that do not require irrigation)
e. erosion-control netting and/or blankets
f. topsoil stockpiling and replacement

Soil hardening – chemical treatment using polymer products that seal the soil, thus binding it to decrease infiltration and permeability and to reduce erosion during and after construction.

In addition to the above possible mitigation measures and those GHU-specific mitigation measures outlined in Table 3A, the following measures should be used anywhere on Snodgrass Mountain where grading, slope shaping and cut and fills will be necessary:

1. Cuts, fills and grading plans should be based on site-specific criteria developed by a geotechnical engineer.

2. Make cuts and fills as small as possible, with no cuts or fills greater than 6 feet high, unless designed by a geotechnical engineer with a safety factor of at least 1.3. A "residual friction angle" should be used for slopes with evidence of previous movement and "fully softened friction angle" should be used for slopes without evidence of sliding (Duncan and Wright, 2005). Cohesion should be "0" for both cases.

3. Incorporate snowmaking meltoff platforms into grading plan.

4. Utilize natural ground surface to extent possible.

5. Capture and control runoff to prevent erosion and saturation of sensitive slope areas.

In the case of slope grading and shaping, engineering design infers the development of criteria for slope gradient, overall cut height and fill depth, soil compaction, pattern and spacing of drainage intercepts, installation of underdrains, and other forms of slope reinforcement as deemed necessary.

c. Potential Effects of Grading and Slope Shaping on Stability of GHU's

Table 3A presents the possible consequences of grading and slope shaping on each of the GHU's. These consequences assume existing conditions without mitigation. The following text further explains these potential effects.

<u>Lower Mountain</u> - (GHU#1, #2, #3, #4, #5)

In the lower portion of Snodgrass Mountain, the effects of grading and slope shaping have the greatest potential for causing slope instability if not carefully designed, executed and maintained. Some examples of these potential impacts are discussed below. The entire West Slide Complex (GHU #1A and #1B) should be considered as having a high risk of increased incidence or accelerated rate of slope movement with any disturbance that increases the driving forces or decreases the resisting forces acting on the slope. If ski trails extended down the upper West Slide to the slightly more gentle slopes of the Lower West Slide, they could be perpendicular to the contours on a steep slope. This may require extensive clearing of trees, mostly aspen but some conifers, and possible grading to reduce slope irregularities. Because of the widespread evidence of recent and current slope movement in this area, constructing such ski trails creates a high risk of accelerating the rate of retrogressive failure up the slope and initiating new slumps and shallow translational landslides in areas of accelerated creep. Grading and slope shaping could be required for ski trails on the upper part of the Lower West Slide (GHU #1B) and on the upper part of the Lower Earthflow. This earthflow is active as evidenced by soil cracks, vertical channel banks with recent erosion, and disrupted vegetation, and the clearing of trees in these portions is likely to accelerate its movement. Surface changes on the earthflow may be minor, but movement of the earthflow could destabilize the steeper slopes above, with the possibility of more dramatic sliding. Also, increases in groundwater levels in the earthflow could cause slumps that transition into smaller earthflows. If a ski trail occurs on the Lower West Slide (GHU #1B), it could require cuts and fills where it crosses the lower part of the Lower Earthflow. Without an engineered design, the probability of causing more movement is high, as this work would be modifying the loads on the crest of the Lower West Slide.

If a ski trail traverses the east, south and/or west slopes of the Slump Block (GHU#2), cuts and fills would need to be constructed with an engineered design. Otherwise, there would be increased risk of reactivation of small slumps on the order of 2 to 4 acres, based on comparison to the area of slumps on the Slump Block evident on aerial photos. Given its position on the mountain, it is possible that a lift terminal and crowd control area could be placed on this GHU, which could require grading and possibly cuts and fills.

The average side slope of the ravine at the upper end of the Middle Slide Complex (GHU #3) is moderately steep and some flattening of the slope may be desired by the proponent. This could require cutting into the lateral scarp near a recent rockslide. The resulting cut could be on unstable and potentially unstable slopes and may intercept shale. Without an engineered design and probably mechanical reinforcement such as rock bolts or anchors it could have a high probability of failure within the lifetime of the ski area due to the required excavation. Whether this would cause reactivation of the slumps is hard to predict. Some of the scarps forming the steep slopes at the base of the Middle Slide Complex have large, poorly vegetated patches indicating movement perhaps within the past 100 years, but no fresh cracks were observed on the lower half of this unit. However, movement of the slumps that created these scarps removed weight from the lower part of the slide complex and decreased the forces resisting retrogressive movement of the slopes above. Grading of the hummocky terrain in the lower portion of the Middle Slide Complex to reduce the steepness of some of the pitches could destabilize the landslides unless properly engineered.

Ski runs could cross the Lower Earthflow (GHU #4) as skiers funnel through this area from the West Slide Complex and the Middle Slide Complex towards the lower portion of the mountain, requiring some grading and minor clearing. Although no evidence of recent movement was observed, the earthflow’s morphology should not be modified in a way that would decrease its stability.

Every effort should be made to leave the Upper East Slide (GHU #5A) undisturbed from grading or clearing. Ski trails and liftlines placed on the Lower East Slide (GHU #5B) could be on the active earthflow portion of the slide. Skiers descending from the East Face and Chicken Bone may need to use a trail constructed adjacent to a narrow gully, at the southern end of where the Upper East Slide and Lower East Slide meet. For the trail to maintain grade, excavation into the lower slope of old slumps and adjacent potentially unstable slopes may be necessary. Alternatively, fill over the upper end of the marginally stable earthflow could be used. Unless these cuts or fills are constructed with an engineered design, there is a high probability of slope failures resulting from development of this area.

<u>Middle Mountain</u> – (GHU #6, #7, #8, #12)

Due to its more gentle slopes, most of the Chicken Bone (GHU #6) area could be developed for intermediate skiing. It is possible that only the heavily forested eastern portion of this unit would be excluded. Within the meadows where there are scattered patches of trees, some grading and clearing may be necessary on the mid-slopes. Grading, if employed, could destabilize slopes anywhere within the Chicken Bone area (GHU #6), unless properly designed. Of particular concern is the slope below the cleared arcuate area near the bottom of the unit. Cutting into the toe of a landslide, even if currently not moving, is likely to reactivate it unless properly engineered.

The present topography of the East Facet (GHU #7) has numerous pitches ranging from 40 to 90%. Flattening these slopes through grading and slope shaping could result in soil being placed on the upper part of old landslides. Even slides that have not moved for several hundreds of years could be reactivated in this way and grading should, therefore, be avoided. Reactivation of even the smaller slumps could destroy many acres of vegetation and topsoil, but reactivation of the entire unit could affect all areas downhill.

Ski area development in the Upper Narrows (GHU #8) may include ski trails along the ridge on the southwestern portion of the unit and in the ravine area of the Unnamed Drainage to connect the Upper Bowl (GHU #9) with the lower slopes. The greatest potential impact from grading would be flattening the side slope by cutting into the south-facing hillside (northeast side of this unit). The series of scarps below the sloping ridge on the eastern edge of the Upper Narrows suggests a bed of shale below the uppermost layer of igneous rock. Again, this bedrock is mapped as dipping to the west into this localized valley, which means that the dip of the bedrock generally follows the slope of the land, creating a potentially unstable condition. Constructing a ski trail, with a significantly flatter side slope than provided by the natural ground (necessary for intermediate skiers), could entail cutting into shale below the igneous rock, creating a potential failure surface on the contact of these two formations. Such a cut in the Upper Narrows may require mechanical stabilization that, to be effective, could be very expensive and may produce a major visual impact on the ground. Even if the cut is in fractured rock, and it does not intercept shale, it may still require mechanical stabilization. Also, if not stabilized, it could create a rock slide or rockfall hazard. Alternatively, the proponent may consider cutting into the slope on the southwest side of Unnamed Drainage for the ski trail. Because the dip of bedding surfaces in the rock is not parallel to the ground surface, a slide of fractured igneous rock over shale is less likely than on the northeast side of the valley. However, mechanical stabilization may still be necessary. Removal of weight from the lower part of the slope on both sides of the drainage could lead to a rock slump, since the material on the lower part of the slope buttresses soil and rock above it.

Keeping a ski trail to just one side of the valley in the Upper Narrows (GHU #8) could generate a tremendous amount of rock waste material that would need to be hauled off-site. Alternatively, the height of cuts and need for mechanical reinforcement may be reduced by filling the valley with the rock waste material. With a combination of cuts and fills, maintaining the Unnamed Drainage may require piping its runoff through over 1,500 feet of buried pipe. It is estimated that any of the above earthwork options could result in removal of at least 10-acres of forested slopes and the valley bottom would become a bedrock or rock rubble surface that could be very difficult to revegetate.

Due to the nature of the terrain and aspect on the East Face (GHU #12), there is good potential for ski runs and a liftline to access these slopes. Ski trails are not likely on the steeper slopes of the East Face, but the rolling terrain of this unit and its northeast aspect that can retain snow, make much of this unit desirable for ski runs. If ski runs are graded to reduce the amount of side hill, they could cut into the landslides previously described in this area. Cuts and fills could destabilize the slide masses above and below the runs, respectively. Because these slides are deep, stabilization may be impractical or, at least, difficult.

<u>Upper Mountain</u> - (GHU #9, #10, #11)
On both the West Face – North (GHU #10A) and the West Face – South (GHU #10B), most of the terrain is moderate to steep and grading may be needed to flatten the steep pitches. This could place additional weight on the lower slopes, which in some cases, are slump blocks and could reactivate larger slides that have not moved for many hundreds of years.

Due to very steep terrain in the North Face (GHU #11), the potential for intermediate ski runs may be limited to the upper edges and eastern corner of this unit. Grading, by removing protective vegetation and altering natural slopes, may lead to additional debris or rock slides on the steeper slopes. Care to avoid the rock slide/avalanche chutes in locating ski runs will be important.

2. CLEARING

a. General Effects of Clearing on Slope Stability

The clearing of trees and tall shrubs is usually required for ski trails, liftlines and, to a lesser extent, lift terminals, buried utilities, roads, and structures. The removal of trees typically increases the amount of snowmelt or rain that reaches and infiltrates the ground in several ways. First, tree branches intercept falling rain and snow, much of which returns to the atmosphere through evaporation and sublimation. Second, snow accumulates in cleared openings more that on the ground below trees due to the interception of precipitation, described above, and wind deposition (drifting). Third, trees remove water from the ground through evapotranspiration. The result of clearing is that more water is available for runoff and infiltration. Additional infiltration over pre-development conditions will increase groundwater levels and decrease slope stability, both locally where the infiltration occurs, and at other locations further along the groundwater flow path.

Soils on the upper part of Snodgrass Mountain are granular and almost all additional snowmelt from the development and operation of a ski area facility will infiltrate into the soil and underlying fractured igneous rock. Due to hummocky topography created by landslides, there are areas with poor or, in the case of undrained depressions, no surface drainage on the lower southeast side of the mountain. Both of these characteristics of Snodgrass Mountain indicate that some or almost all, additional snowmelt will infiltrate into the subsurface and decrease the stability of slopes.

Within a few years after clearing of conifers, the remaining root structure decays and no longer reinforces soil and weathered rock on steep slopes with thin overburden. If the slopes are only marginally stable, such as those exhibiting the characteristics of accelerated soil creep, shallow landslides may transition into debris slides or earthflows with the loss of root structure. For deeper landslides such as larger slumps and earthflows, the loss of root reinforcement probably does not significantly reduce their stability. However, even over a period of only several years, deep-seated landslides, such as earthflows on moderate slopes, can increase their movement due to small increases in annual precipitation. There may be some advantage to cutting trees flush with the ground surface and leaving root structures intact, so that the roots can temporarily reinforce the slope by providing structural support until they gradually decay, thus providing short-term enhancement of soil stability. The gradual decay of root material can also supply nutrients to the developing plant community. However, once this decay is complete, there is no longer any soil support. This method of mitigation is, therefore, regarded as a temporary aid in the revegetation process, not as a permanent solution to stabilizing cleared areas.

b. Typical Mitigation Measures for Clearing

As mentioned, clearing can be partially mitigated by leaving stump and root systems, using equipment that minimizes disruption of the soil surface, and the use of berms, swales, hay bales, fences, and fiber rolls to control runoff and limit erosion. Clearing should not be conducted in early spring when the soil is soft and susceptible to rutting and pumping (i.e., soft ground deformation under moving loads). All cleared areas should be revegetated as quickly as possible. On-site chipping of limbs and woody debris will reduce driving and dragging activities required to truck these materials from the site or to stack them into burn piles.

In addition to the GHU-specific mitigation measures outlined in Table 3B, the following measures should be used anywhere on Snodgrass Mountain where clearing will be necessary:

1. On historic slides or accelerated creep areas, clearing should be generally limited to individual trees or just enough trees to connect existing openings.

2. Limit clearing whenever possible.

3. Use equipment appropriate to the task so that disturbance is minimized.

4. Control erosion and make sure runoff is not concentrated towards less stable areas.

5. Revegetate disturbed areas as soon as possible.

c. Potential Effects of Clearing on Stability of GHU's

Table 3B presents the possible consequences of clearing trees on each of the GHU's. These consequences assume existing conditions without mitigation. The following text further explains these potential effects.

<u>Lower Mountain</u> - (GHU #1, #2, #3, #4, #5)
Clearing could be required for ski trails on the upper part of the Lower West Slide (GHU #1B) and may also require clearing of conifers and some aspen on the upper part of the Lower Earthflow. The removal of trees is likely to accelerate movement of the Lower Earthflow. Surface changes on the earthflow may be minor, but movement of the earthflow could destabilize the steeper slopes above and could lead to more dramatic sliding. Also, increases in moisture infiltration into the earthflow could cause slumps that transition into smaller earthflows. On the Slump Block (GHU#2), clearing could destabilize the slopes causing small slumps on the order of 2 to 4 acres.

Given the topography, a ski trail could be cleared northeast of the Unnamed Drainage in the narrow ravine at the upper end of the Middle Slide Complex (GHU #3). This may require clearing and possibly liftlines on the series of scarps and slump blocks of this GHU. Infiltration is likely on all but the steeper scarps. Clearing will reduce evapotranspiration and also result in an increase of groundwater levels. Since clay and shale slopes lose strength with time, clearing could increase the probability of renewed slope movement during the life of the ski area. Additional moisture from clearing on and upslope of the Lower Earthflow (GHU #4) could initiate or accelerate movement of the earthflow.

<u>Middle Mountain</u> – (GHU #6, #7, #8, #12)
Due to the topography and position of the East Facet (GHU #7) on the mountain, clearing for ski trails may be needed to develop this slope. Ski runs and liftlines could cut straight down the hillside, perpendicular to slope contours, concentrating runoff and allowing erosion. On the steeper slopes, where soil cover is likely to be thinner, loss of root reinforcement resulting from clearing conifers for ski trails and liftlines also will decrease stability. The increased infiltration of the porous soils of this unit will allow greater infiltration of cleared areas and a decrease in slope stability.

Cutting trees would increase infiltration into the ground and likely decrease slope stability in the Upper Narrows (GHU #8) as well as downslope in the Chicken Bone (GHU #6). For the East Face (GHU #12), clearing for trails and a liftline could increase the rate, duration and frequency of future movement because there is extensive evidence of recent movement. This clearing may decrease the stability of slopes. Also, on steeper slopes, areas of accelerated creep, or slow movement of slumps, could change to rapid movement and larger displacement. On the steeper slopes in this unit, landslides have cleared much of the forest cover, which may be developed with very little clearing. Where the forest cover is thicker, the slopes are generally more gentle. However, extensive tree clearing could be necessary.

<u>Upper Mountain</u> - (GHU #9, #10, #11)
Given the proximity of the Upper Bowl (GHU #9) to the summit of Snodgrass Mountain and its desirable ski terrain, clearing for ski trails may be necessary. Although the relatively gentle slopes and lack of evidence of previous mass movement in the Upper Bowl suggests that an increase in infiltration from clearing is not likely to initiate landslides in that unit, it could have downhill impacts. Such drainage patterns could raise groundwater levels and decrease slope stability in the Upper Narrows (GHU #8), Chicken Bone (GHU #6), West Slide Complex (GHU #1), Middle Slide Complex (GHU #3), and Lower Earthflow (GHU #4), as well as outside of the permit area on the southwest side of Snodgrass Mountain towards Washington Gulch due to the dip of the bedrock.

On both the West Face – North (GHU #10A) and the West Face – South (GHU #10B), a number of runs and a liftline could extend from the summit of Snodgrass Mountain to the gentle slopes of the valley floor. Clearing trails in areas of accelerated creep, which is extensive throughout the West Face – South unit (GHU #10B), could cause shallow landslides that transition into earthflows. These creep areas are close to failure now and the loss of root reinforcement, combined with an increase in snow accumulation and meltwater, could result in slope failures similar to what has occurred in the recent past. In the West Face – North (GHU #10A) unit, clearing could cause greater infiltration into the soils and reactivation of the rock slumps at the contact of the granular igneous rocks with shale. This could lead to or accelerate retrogressive failure up the slope.

Due to very steep terrain in the North Face (GHU #11), any tree removal will result in the eventual loss of root reinforcement and almost certainly lead to additional debris or rock slides on the steeper slopes. Clearing could also increase the size of snow avalanches that appear to currently reach Gothic Road via narrow, but well-established chutes, unless counterbalanced by the stabilizing effects of skier traffic and avalanche control practices.

3. SNOWMAKING

a. General Effects of Snowmaking on Slope Stability

Due to its mostly south-facing aspect and elevation, the proposed ski area on Snodgrass Mountain will likely require snowmaking on selected runs and at the lift terminals. Snowmaking operations, although not applied to the entire mountain, add moisture to slopes, which can infiltrate through the soils and into the groundwater system. The hydrologic processes are similar to those described above under clearing. Increased groundwater will increase the load within the slope and lower soil strength. In effect, it is changing the microclimate of discrete areas to one that is wetter. Even over a period of only a few years, deep-seated landslides, such as earthflows on moderate slopes, can increase their movement due to small increases in annual precipitation. Understanding the impacts of snowmaking on a complex natural system that is marginally stable is not well known. In the abstract for a presentation at a Geological Society of America (GSA) meeting, Jim McCalpin wrote "Unfortunately there have been no rigorous experiments on the effect of ski trail cutting or artificial snowmaking, on slope stability......Until such work is done, predicting the effects or trail clearing and snowmaking on slope stability will have to rely on qualitative estimates and "professional judgment".

Soils on the upper part of Snodgrass Mountain are granular and a large proportion of the additional snowmelt from development and operation of the ski facility will infiltrate into the soil and underlying fractured igneous rock. Due to hummocky topography created by landslides and clayier soils derived from the Mancos Shale, there are areas with poor or, in the case of undrained depressions, no surface drainage on the lower southeast side of the mountain. Both of these characteristics of Snodgrass Mountain indicate that additional snowmelt will infiltrate into the upper portions of the mountain and daylight in the lower sideslopes below the permeable laccolith cap. This drainage characteristic of the mountain will decrease the stability of slopes.

To understand the possible impacts of snowmaking on Snodgrass Mountain an estimate of the quantity of water is helpful. CBMR Mountain Manager, Roark Kiklevich, has provided the Forest Service with information about snowmaking amounts per acre, as follows. Industry Standards are 180,000 to 200,000 gallons per acre for 12 inches depth of snow base. CBMR uses the average of 190,000 gallons for Crested Butte Ski Area. CBMR expects to make 12 inches of snow on some of Snodgrass and 24 inches on other portions of Snodgrass. Snow is typically made early in the season in an effort to create a base upon which natural snow can accumulate. Ideally, in ski seasons with higher than average snowfall, less snow would need to be made, but in years with lower than average snowfall, more snow would need to be made. Either way, the effect would be that the mountain never has a dry winter. Realistically, the ski area will make most of the snow during the fall and early winter before anyone knows how wet the later months will be. Currently, CBMR does not know where snow will be made on Snodgrass Mountain and to what depth. However, any slope with a southerly exposure and that is lower on the mountain will likely need more snow than what nature will typically provide. Most of these slopes are on the southeast- and south-facing slopes, such as the Slump Block, Lower West Slide Complex, Lower East Slide and Middle Slide Complex.

For the purposes of converting snow depth to water equivalent, the assumption by M. Burke is that there is 6.4 to 7.1 inches of water per 12 inches of man-made snow. Artificial snow has significantly higher moisture content than natural snow in Colorado, which has moisture content of roughly 1 inch of water per 12 inches of snow. Using these man-made snow moisture contents, and considering a minimum of 24-inches of man-made snow over the full ski season, this would produce approximately 13 inches of water. Considering the southern exposure of these slopes, it could be more. According to the Natural Resources Conservation Service (NRCS) website “Snotel” (*www.wcc.nrcs.usda.gov\snow*), the 24-year average (from 1982 to 2005) of yearly precipitation at the closest weather station, located at an elevation of 10,160 feet on the Crested Butte Ski Area, is 27 inches. (In this 24-year period, the lowest yearly precipitation was 19 inches in 2002 and the highest was 38 inches in 1984.) Using the yearly average for the previous 24-years, this means that for an area that receives roughly 27 inches of precipitation per year, 13 inches of additional water is a substantial increase. In essence, it is increasing the amount of moisture by 48% on the slopes where snow is artificially made. To truly understand its impact, this amount of water per acre would need to be applied to a hydrologic model of the mountain. Once the hydrology is understood, this information can be applied to slope stability analyses for each GHU. It has also been observed that slow melting of large banks of man-made snow (as in snowboard parks and ski jumps) causes soil saturation, which combined with the weight of the snow bank, can cause localized slope failure.

There are no published studies on the quantitative impacts of snowmaking on slope stability. Each natural system is unique and the geologic setting and hydrology control runoff and groundwater flows. However, on top of the complex natural system is proposed tree clearing, grading, and modifications to natural drainage patterns. The consensus of professional geologic opinion is that snowmaking, unless mitigated, increases the risk of additional slope failures on Snodgrass Mountain (expressed in various ways by RCE, Baum, McCalpin, CSA, and Burke).

Extensive snowmaking on obvious landslide masses that show evidence of recent movement is a very high risk proposition. Therefore, it becomes a question of the effectiveness and practicality of mitigation on a large area with complex and, as of now, poorly understood patterns of groundwater flow. Surface drainage was discussed by McCalpin in his "stability neutral" plan (McCalpin, 2005) to drain critical portions of the mountain. However, surface drainage alone may not adequately address the drainage problem. Therefore, controlling subsurface drainage will also be important in designing a mitigation plan. However, it is well known that, due to its poor internal drainage, subsurface drains installed in clay soils are very hard to design with a high degree of reliability. An integration of both surface and subsurface drainage plans will be important for effectively collecting and removing the added moisture brought to the mountain by snowmaking.

b. Typical Mitigation Measures for Snowmaking

The use of surface drains, intercept drains and horizontal drains to capture runoff throughout Snodgrass Mountain is recommended. These drainage features must be incorporated into a mountain-wide drainage plan integrated with all proposed development elements. To reduce the amount of water that would need to be drained, an effort should be made to limit snowmaking wherever possible. Limiting snowmaking should be considered the primary mitigation method.

Mechanical snow removal at the end of the ski season is another mitigation method that can be employed in particularly sensitive areas. Snow should be stockpiled in designated areas having specially designed surface and subsurface drains so that the meltwater will be removed in ditches and/or drains and infiltration into potentially unstable soils and slopes is restricted.

In addition to the GHU-specific mitigation measures outlined in Table 3C, the following measures should be used anywhere on Snodgrass Mountain where snowmaking is proposed:

1. Snowmaking should be avoided, wherever possible, to reduce the amount of water that would need to be drained.

2. Specially constructed surface and subsurface drains should be used to protect sensitive areas or areas designated for stockpiling and meltoff. See "Typical Mitigation Measures for Grading and Slope Shaping" (Section VI.B.1.b.) for examples of surface and subsurface drain options.

3. A mountain-wide drainage plan, integrated with the grading plan, would need to be implemented.

4. Control sediment runoff.

5. Wetlands impacts need to be accounted for in draining snowmaking areas. A hydro-geologic connection would need to be established to understand the mechanisms for recharge of the wetland areas so that draining slopes where man-made snow is produced do not negatively impact the health of the wetland areas.

6. Regulate snowmaking to dovetail with natural snow accumulation to ensure that a maximum snow depth is not exceeded.

7. Develop an active monitoring program during the spring snowmelt season to evaluate the effectiveness of drain systems and to repair them immediately when they clog/fail.

c. Potential Effects of Snowmaking on Stability of GHU's

Table 3C presents the possible consequences of snowmaking on each of the GHU's. These consequences assume existing conditions without mitigation. The following text further explains these potential effects.

Lower Mountain – (GHU #1, #2, #3, #4, #5)
Snowmaking in the area of the Lower West Slide (GHU #1B) and Lower Earthflow (GHU #4) could accelerate movement of the Earthflow. Movement of the earthflow could destabilize the steeper slopes above it and this could lead to more dramatic sliding. Also, increases in groundwater levels in the Earthflow could cause slumps that transition into smaller earthflows. Snowmaking anywhere on the Lower Earthflow would likely increase the probability of this happening. On the Slump Block (GHU#2), clearing could destabilize the slopes causing small slumps on the order of 2 to 4 acres. Snowmaking both above and on the Middle Slide Complex (GHU #3) has the potential for high risk of movement of this landform, as well as those below it (primarily the Lower Earthflow and Slump Block) without aggressive mitigation. Snowmaking would increase the total amount of water reaching the ground surface for infiltration and runoff when the snow melts. Infiltration is likely on all but the steeper scarps. Since moisture availability generally accelerates weathering and loss of strength over time, snowmaking could increase the probability of renewed slope movement during the life of the ski area. Additional moisture from snowmaking and clearing on and upslope of the Lower Earthflow (GHU #4) could initiate or accelerate movement of the Earthflow.

Snowmaking on the Upper East Slide (GHU #5A) would almost certainly increase the infiltration of meltwater into the ground and increase the magnitude and frequency of movement of the marginally stable earthflow. There are many wetlands in the Chicken Bone (GHU #6) unit above the Middle Slide Complex and in the drainage of the Middle Slide Complex, indicating shallow groundwater levels naturally in these areas. Movement of the Middle Slide Complex could trigger the movement of downhill units as well as cause retrogressive failures into the

Chicken Bone. Snowmaking on the Lower East Slide (GHU #5B) creates a high probability of additional slope movement from operation of the ski area. Accelerated movement of the earthflow would remove material from the base of the upper slide and could cause renewed retrogressive failure to progress up the hill to the uppermost scarp of the Upper East Slide and, possibly, beyond.

<u>Middle Mountain</u> – (GHU #6, #7, #8, #12)
The general shape of the Chicken Bone (GHU #6) unit is a south-facing bowl with elevations ranging from 10,100 to 10,400 feet. Snowmaking, could decrease slope stability both within and downslope of Chicken Bone. The absence (or scarcity) of fresh cracks through most of the area suggests there is little current slope movement and that some increase in groundwater levels could be tolerated without major renewed movement under a continuation of recent climatic conditions. Additional surface and subsurface flow from the area, however, could reach the Middle Slide Complex (GHU #3) and the West Slide Complex (GHU #1) and may contribute to reactivation of slides in those areas.

Since few surface drainage channels exist in the East Facet (GHU #7), due to coarser soils and greater permeability, almost all additional snowmelt would infiltrate into the ground and likely decrease the stability of the slopes. Also, groundwater levels downslope in the Chicken Bone (GHU #6) and East Face (GHU #12) areas could increase and slope stability could decrease there, as well. Increased infiltration would likely decrease slope stability in the Upper Narrows (GHU #8) as well as downslope in the Chicken Bone (GHU #6).

<u>Upper Mountain</u> - (GHU #9, #10, #11)
Because of the relatively gentle slopes and lack of evidence of previous mass movement within the Upper Bowl (GHU #9), an increase in infiltration from snowmaking is not likely to initiate landslides. The upper part of the Unnamed Drainage (from just above Ken's Crux to the Upper Bowl) does not appear to carry much surface flow due to the permeable nature of the soil and rock. Therefore, almost all infiltration of rain or snowmelt will flow as groundwater to other parts of the mountain. Assuming a simple groundwater model of water infiltrating the porous laccolith cap and daylighting at or near the underlying, clayey and less permeable Mancos Shale contact, snowmaking would increase the amount of water that infiltrates the ground. This would raise groundwater levels and decrease slope stability in the Upper Narrows (GHU #8), Chicken Bone (GHU #6), West Slide Complex (GHU #1), Middle Slide Complex (GHU #3), and Lower Earthflow (GHU #4). Due to the dip of the bedrock to the west, it could also increase the water delivery to and decrease the stability of slopes outside of the permit area on the southwest side of Snodgrass Mountain towards Washington Gulch.

Snowmaking on the West Face – South (GHU #10B) could add sufficient moisture to slopes with accelerated creep to transition them into shallow landslides and earthflows. The increase in snow accumulation and meltwater could also contribute to elevated groundwater levels in the Washington Gulch area. In the West Face – North (GHU #10A) unit, snowmaking could cause greater infiltration into the soils and reactivation of the rock slumps at the contact of the granular igneous rocks with shale. This could lead to or accelerate retrogressive failure up the slope.

Although it is not likely that snow would be made on the very steep, North Face (GHU #11), additional snow could increase the size of snow avalanches that drop via narrow chutes from near the ridgeline down to Gothic Road. Efforts would need to be made to reduce the avalanche risk with effective skier traffic and avalanche control practices.

4. BURIED UTILITIES

a. General Effects of Buried Utilities on Slope Stability

Utility trenches break the continuity of a slope, creating an artificial line of weakness that can contribute to slope instability. Buried utilities can also decrease or increase slope stability by modifying subsurface water flow paths. If the trench intercepts a seasonal groundwater table and backfill is more permeable than the natural ground due to poor compaction or coarser gradation, subsurface water could be diverted to, and concentrated at, a marginally stable location and induce landsliding. On the other hand, the stability of the area may increase if it is drained by a utility trench. If the backfill is less permeable than the natural soils it may impede subsurface flow, increase groundwater pore pressure uphill of the trench, and initiate or reactivate slope movement. Additionally, slope movement, whether induced by a buried utility trench or not, can impact utility pipelines or cables by shearing or rupturing them. In the case of water pipelines, this is not only a maintenance issue, but also there is risk of saturating the soils from leakage or ruptures that will cause a loss of soil strength resulting in erosion and/or slope failure. The use of flexible pipelines, alarm systems with automatic shutoffs, and careful monitoring of water usage can assist in detecting and mitigating these leaks. In areas where snowmaking will be used, a network of buried waterlines would be expected, so the protection of these pipelines will be very important.

Another potentially adverse effect can be from linear trench excavations. These can inadvertently undercut unstable slopes or create an artificial head scarp that initiates downslope failure. In other words, by disrupting the native soil conditions (composition, compaction, permeability, etc.) along a vertical plane, inherently creates a zone of weakness. It is along this zone that future failures can occur, if not properly designed constructed. Therefore, a slope stability analysis is recommended to evaluate the effects of proposed trenching across the active (Age Class 1) slopes.

b. Typical Mitigation Measures for Buried Utilities

In addition to the GHU-specific mitigation measures outlined in Table 3D, the following measures should be used anywhere on Snodgrass Mountain where buried utilities are proposed:

1. Use trenches as underdrains to intercept groundwater flow in sensitive areas.

2. Minimize wetland crossings.

3. Backfill trenches with material that has greater density and lower permeability than the native material. Also, use an impermeable cap in the upper 1 to 2 feet of trench backfill.

4. Construct diversion bars to deflect runoff from trenches and reduce infiltration.

5. Whenever possible, create combined access corridors in the most favorable locations as concentrated routes for roads, trails, and buried utilities. This will minimize site disturbance, offer easy access for utility maintenance, and will facilitate erosion control and revegetation.

6. Construct trenches during the dry time of the year (late summer through fall) to reduce risk of trench collapse during construction due to saturated soils.

c. Potential Effects of Buried Utilities on Stability of GHU's

Table 3D presents the possible consequences of buried utilities on each of the GHU's. These consequences assume existing conditions without mitigation. The following text further explains these potential effects.

Lower Mountain - (GHU #1, #2, #3, #4, #5)
The upper portion of the Upper West Slide (GHU #1A) contains bedrock scarps and shear zones that should be avoided with the alignment of buried utilities so that these features are not disrupted and do not inadvertently receive additional water. The utility trenches could serve as conduits for water transport, thus delivering water to sensitive areas that could be reactivated. In both the Upper and Lower West Slide (GHU's #1A and 1B), slumps could transition to earthflows and failures in the lower portion of this complex could retrogressively fail uphill into the upper unit. The same effects could occur in the East Slide Complex (GHU's #5A and 5B). However, in this area, the consequences could be more severe due to the well-developed slump block features in the upper portion of this unit and the active earthflow features of the lower unit. If broken water lines saturate the soils or poorly designed trench backfill delivers water to the Lower East Slide (GHU #5B), this could cause the acceleration of movement of the earthflow, which may be rapid, and it could remove support of the Upper East Slide (GHU #5A) and initiate retrogressive failures upslope. The series of scarps and benches in this upper unit attests to this form of failure in the past and its zones of weakness for future failures.

Additional water delivered by porous utility trenches or broken waterlines to the other units at the bottom of the southeast portion of the mountain (the Slump Block – GHU #2 and the Lower Earthflow – GHU #4) would have similar consequences as just described. These units could become active earthflows which could be rapid, and their movement would remove the support of the Middle Slide Complex (GHU #3), possibly causing retrogressive failures of slump blocks in this unit. The Middle Slide Complex has a buttresses effect on a portion of the West Slide Complex (GHU's #1A and 1B) and the Chicken Bone (GHU #6) unit. Essentially, earthflow movement of the lowest units could destabilize the Middle Slide Complex, which could release support of uphill units, causing a retrogressive chain reaction. The probability of slope movement due to disturbance with buried utilities in the lower mountain is, therefore, considered to be moderate to high without aggressive mitigation to control water delivery to sensitive slopes.

<u>Middle Mountain</u> – (GHU #6, #7, #8, #12)
As just discussed, the stability of the middle mountain is strongly controlled by movement in the lower mountain. Portions of the middle mountain contain extensive wetlands, such as in Chicken Bone (GHU #6) and the East Face (GHU #12). These areas indicate poor drainage, heavy clay soils, and possibly a confining layer like shale. Care will need to be taken when designing and constructing trenches in these wet areas as well as near slope failure features so that water is not delivered to sensitive areas within these units as well as downhill to the lower mountain. The East Facet (GHU #7) and the Upper Narrows (GHU #8) are probably the least sensitive to slope movement initiated by utility trenches due to their permeable soils. However, water infiltration here can cause problems downhill.

In general, most units within the middle mountain have low probability of inducing slope movement if typical mitigation measures, suggested above, are following. However, the East Face (GHU #12) has moderate probability of movement because it has characteristics of both the middle mountain (slump blocks) and lower mountain (earthflows). A portion of this unit contains an extensive landslide mapped by Soule (1976). If the earthflow landforms become saturated by concentrated drainage from utility trenches, their failure could be rapid and the loss of support in the upper portion of this unit could cause retrogressive failures up into the East Facet (GHU #7).

<u>Upper Mountain</u> - (GHU #9, #10, #11)
The units in the upper mountain drain the upper portion of the mountain in all directions and generally contain permeable igneous-derived soils that are regarded as stable. Although the probability of slope movement induced by utility trenching in the upper mountain is considered to be low, the flow of water via utility trenches to the lower flanks of the mountain could be problematic. Little development is planned for the North Face (GHU #11), but both the West Face units (GHU's #10A and 10B) and the Upper Bowl (GHU #9) would likely be extensively developed and will therefore need utility trenches. The inadvertent delivery of water downhill to the more sensitive slopes, via poorly constructed trenches or broken waterlines, could lead to earthflows and reactivated slumps in the lower flanks of the mountain.

5. ROADS

a. General Effects of Roads on Slope Stability

Access roads are a necessary part of ski area development and maintenance. They can also serve as ski trails to connect the larger ski runs. The construction of roads on a ski slope generally requires cuts on the uphill side of the road and fills on the downhill side. Care should be taken to balance the cuts and fills so that weight distribution on the slope after construction is less than or equal to the natural loads. Also, careful placement of the roads is necessary to avoid areas of high hazard for slope movement. Please see above sections on Grading (VI.B.1) and Clearing (VI.B.2) for discussions about preserving slope stability for these activities. Cuts on the uphill side of a road strip the hillside of vegetation and fills on the downhill side covers vegetation and changes the weight distribution on the slope. Keeping roads as narrow as possible and revegetating these disturbed areas will be very important for reducing erosion, binding the surface soils with roots, absorbing excess water that infiltrates into the soils, and reducing visual impacts.

Typically, roadcuts are laid back into the hillside and at an angle that creates stable conditions and permits revegetation, which is often at an angle of 2:1 (horizontal:vertical) or less for cohesive (clayey) soils. When this layback angle is not possible due to steep slopes above the road or the presence of structures or buried utilities that could be undermined, the cut slope would need to be retained. The options for slope retainage depends on the composition of the soil materials, extent of the cut slope, drainage concerns, and desire for aesthetic appearance of the finished wall. Geotechnical testing would be necessary to characterize subsurface soil, bedrock and groundwater conditions at wall sites, and then a slope stability analysis would be needed to determine the appropriate options for slope retainage. It is likely that boulder stacks, soil nails, and tie-back systems would be the most common methods used at this site. These systems essentially pin the wall to the hillside and bind or stiffen the supporting soils with a grid of deep anchors. Once the cut slope is stabilized, it can be dressed with soil and revegetated or faced with rock or a concrete faux (rock simulated) finish. Drainage systems designed into the wall would be essential to capture surface and subsurface water and deliver it to a road drain system. Water pressure building up behind these walls could cause failure of the walls and/or failure of the slope at and around the wall.

Fill for access roads on gentle slopes is not generally severe, but as the grade of the slope being traversed by the road increases, the fill amounts also increase. Again, balancing cuts and fills is essential on potentially unstable slopes. In order to achieve this balance in areas with deep fills, there are light-weight man-made products that can serve as fill material to reduce the loads on a slope. This might be a very effective option on sensitive slopes. Placement of fills would need to be carefully controlled (compacted to specified densities and moisture contents) during construction to reduce the potential for settlement, fill failures, or unintended seepage into the fill. In areas with deep fills, which do not tie into the slope, an alternative to a compacted fill slope, is the use of Mechanically Stabilized Earth (MSE) fills or engineered walls such as Hilfiker Walls. This latter type of wall system uses geogrids or wire mesh that can tie into the slope. In addition to allowing for a vertical or near-vertical wall that has a connection with the slope, the downhill extent of the wall is minimized, thus reducing the impacts to the native vegetation. Light-weight man-made material may be used as some of the fill in this system to reduce loads. As with deep cuts along a road, deep fills impact the native vegetation and the new slope would need to be revegetated and protected from erosion. Drainage from these fill slopes would also have to be carefully managed to not concentrate runoff downhill of the fill, thus potentially destabilizing it.

b. Typical Mitigation Measures for Roads

Cuts and fills are necessary for constructing access roads on sloping terrain within a ski area. Typical mitigation measures discussed in the *Typical Mitigation Measures for Grading and Slope Shaping* (Section VI.B.1.b) also apply to road construction.

In addition to the GHU-specific mitigation measures outlined in Table 3E, the following measures should be used anywhere on Snodgrass Mountain where roads are proposed:

1. Avoid riparian zones and wetlands.

2. Minimize road width and cuts and fills. Balance cuts and fills so that weight distribution on the slope after construction is less than or equal to the natural loads. Use light-weight man-made materials, if necessary, to achieve this balance.

3. Control erosion and provide revegetation.

4. Possible weak subgrade conditions may require removal and replacement of soils, geofabrics, and subdrains. These improvements would need to be designed by a geotechnical engineer in compliance with the drainage and grading plans.

5. Provide culverts and structures sized and located in compliance with drainage plan.

6. Use erosion-resistant surfaces such as gravel, magnesium chloride, and soil cement.

7. Design roads to roll with the terrain as much as possible.

c. Potential Effects of Roads on Stability of GHU's

Table 3E presents the possible consequences of roads on each of the GHU's. These consequences assume existing conditions without mitigation. The following text further explains these potential effects.

<u>Lower Mountain</u> – (GHU #1, #2, #3, #4, #5)
Due to the steeper slopes of the Upper West Slide (GHU #1A) and the Upper East Slide (GHU #5A), road construction is considered to have a high probability of causing slope movement without aggressive mitigation. The Lower East Slide (GHU #5B) is also at high risk due to the anticipated need for reinforcement and stabilization of weak soils including possibly shale. Avoidance of all or parts of these areas with roads are recommended. In the other areas of the lower mountain, the probability of movement is moderate due to the need for multiple mitigation measures to control drainage from roads, engineer cuts and fills, and the design of slope retention systems. Slope stability analyses would be necessary to assess the options for slope retention and the potential impacts of disturbing these sensitive slopes with cuts and fills.

<u>Middle Mountain</u> – (GHU #6, #7, #8, #12)
All four of the middle mountain GHU's are considered to have moderate potential for inducing slope movement with the construction of roads without multiple mitigation measures. This is because the generally steeper slopes of the middle mountain will likely require uphill slope stabilization and downhill engineered fills and retaining structures. The existing access road successfully traverses this portion of the mountain with few problems. Rather than disturb new areas, it is suggested that the same alignment be incorporated into the overall transportation plan so that it is improved and only realigned around sensitive or problem areas. The Chicken Bone (GHU #6) with its extensive wetlands, could prove difficult for road construction due to saturated and weak soil conditions. Special roadbase preparation may be necessary and not impeding surface and subsurface water flow will be important. For the East Facet (GHU #7), the Upper Narrows (GHU #8), and the East Face (GHU #12), using roadway corridors for the alignment of buried utilities is recommended to keep the excavations to well-studied and mitigated disturbed areas.

<u>Upper Mountain</u> – (GHU #9, #10, #11)
For the Upper Bowl (GHU #9) and the West Face – North (GHU #10A), the probability of slope movement induced by roads is considered to be low and mountain-wide mitigation for road construction, as suggested above (Section VI.B.5.b.), should be sufficient for maintaining slope stability. However, for the West Face – South (GHU #10B) and the North Face (GHU #11), the risk of movement is considered to be moderate, due to the more sensitive nature of these units to disturbance. Therefore, additional mitigation measures are recommended to ensure the proper placement, design, and construction of roads. The West Face – South (GHU #10B) has accelerated creep areas that could progress to earthflows with concentrated runoff from roads or poor placement of roads that cut the toe of a slope and apply fill loads to the crest of slopes. The proposed ski area only covers a small area of the North Face (GHU #11) and it is generally steep to very steep. Roads may be able to be avoided in this area altogether. Concentrated runoff from roads in this unit could cause further erosion of the rock slide/avalanche chutes that run from the summit and ridgeline of Snodgrass down to Gothic Road.

6. LIFTLINES (TOWERS AND TERMINALS) AND STRUCTURES

a. General Effects of Liftlines and Structures on Slope Stability

Generally, the construction of properly designed structures such as liftline towers, terminals and buildings do not contribute to slope instability. However, their construction (roads to these sites, cuts, fills, foundation excavations) can. These aspects were previously discussed with other activities such as grading and slope shaping, clearing, and roads. Although slope movement can damage structures, mitigation to reduce loss of structures is an issue for the ski area, not a fundamental concern for preserving slope stability. Measures designed to protect structures should be incorporated into the overall plan for mitigating slope movement for the other ski area activities.

b. Typical Mitigation Measures for Liftlines and Structures

Because cuts and fills are necessary for constructing access roads to liftline towers and building pads for terminals and other structures on sloping terrain within a ski area, typical mitigation measures discussed in the *Typical Mitigation Measures for Grading and Slope Shaping* (Section VI.B.1.b) apply.

In addition to the GHU-specific mitigation measures outlined in Table 3F, the following measures should be used anywhere on Snodgrass Mountain where liftline towers, terminals, and other structures are proposed:

1. Avoid riparian zones, drainages and wetlands. Span them whenever possible.

2. Pin structures to bedrock to avoid loading potentially unstable overburden materials.

3. Site-specific geotechnical investigations and soil testing are recommended for all terminals and structures to design appropriate foundation systems for soil and slope conditions. Testing for liftline towers would also be important, especially for towers on active (Age Class 1) slopes and wherever soil, groundwater or slope conditions are problematic.

4. Slope stability analyses, based on site-specific geotechnical subsurface testing, is recommended for terminals and structures.

5. Span active slopes by placing towers on adjacent, more stable slopes.

6. Consider impacts of clearing beneath lift lines when designing lift alignments.

c. Potential Effects of Liftlines and Structures on Stability of GHU's

Table 3F presents the possible consequences of liftlines and structures on each of the GHU's. These consequences assume existing conditions without mitigation. The following text further explains these potential effects.

<u>Lower Mountain</u> – (GHU #1, #2, #3, #4, #5)
Given the location of the Middle Slide Complex (GHU #3), it is possible that a liftline would traverse the series of scarps and slump blocks of this GHU. Careful placement of towers and access roads to avoid known scarp areas will be important. Damage to towers is likely in the event of movement of the Middle Slide Complex.

If a lift terminal is placed on the upper portion of the Lower Earthflow (GHU #4), it could require localized grading. Although the terminal probably would not destabilize the slope, soils would likely be soft and compressible. If movement did occur of the earthflow, perpendicular to the lift alignment, this could be problematic. Grading and construction on the Lower East Slide (GHU #5B) could cause localized failure on the earthflow. However, construction of lift towers is not likely to contribute to additional movement of the earthflow, but they could be damaged by slope movement. This could cause towers to become misaligned and require maintenance or replacement.

<u>Middle Mountain</u> – (GHU #6, #7, #8, #12)
If a liftline crosses the southern end of Chicken Bone (GHU #6), towers could be located on a portion of the possible earthflow that parallels the main drainage. Construction of the lift would not significantly increase the loading of the slopes but slope movement, either natural or exacerbated by development, could cause maintenance problems.

Due to the topography and position of the East Facet (GHU #7) on the mountain, it is possible that one or more liftlines would utilize this terrain. Clearing for liftlines may cut straight down the hillside, perpendicular to the slope, and would have the same effects caused by less tree cover as discussed under the "Potential Effects of Clearing" section. The construction of liftlines could also have the effect of decreasing slope stability due to the increased infiltration of the porous soils of this unit that can be delivered to downhill units. Cuts and fills associated with the construction of access roads and towers would need to be carefully designed so as to preserve slope stability.

At least one lift may be necessary to access the broad East Face (GHU #12). Liftline(s) could cross numerous recent landslides at an angle and slope movement could cause serious maintenance problems including tower replacement. The failure surfaces are probably quite deep and founding the towers on stable bedrock is recommended, but probably not practical.

<u>Upper Mountain</u> – (GHU #9, #10, #11)
A liftline that accesses the summit of Snodgrass Mountain from the southeast could require traversing the Upper Bowl (GHU #9). Provided that site-specific foundation investigations are conducted, and the recommendations from those geotechnical investigations are followed in design and construction, there should be minimal problems with slope movement for towers, terminals, or structures.

Constructing liftlines in areas of accelerated creep, which are common in the West Face – South (GHU #10B), could cause shallow landslides that transition into earthflows. These creep areas are marginally stable, so cuts and fills associated with the construction of access roads and towers, could result in slope failures similar to what has occurred in the recent past. Based on field surveys and the interpretation of aerial photographs, there is an extensive earthflow deposit on the West Face – South (GHU #10B) that contains accelerated creep areas. Consequently, if a liftline is placed on this unit, towers would need to be on firm bedrock, not the fractured rock near the surface. The lifts should also be designed to resist the impact of earthflows. This unit is, therefore, considered to have high risk for slope movement due to disturbance for liftlines and structures if not aggressively mitigated.

C. Geologic Hazard Risk Assessment

Assessment of geologic hazard risk includes two components: probability of occurrence and severity of consequences. With regard to natural landslides subject to destabilization by proposed ski area development, the probability of occurrence is difficult, if not impossible, to accurately quantify and the severity of consequences is subjective, depending on the interests and values of affected parties. With regard to ski area development, risk of development on potentially unstable slopes includes the risk to human safety, risk of damaging the natural environment, and risk of damage to ski area facilities. In the case of Snodgrass Mountain, landslides are a naturally occurring process, but the central questions are what areas of the mountain are potentially most sensitive to movement when disturbed by ski area activities, what activities have the possibilities of inducing slope failures, and what are the most effective mitigation measures needed to reduce this risk? A series of risk assessment tables (Tables 3A through 3F in Appendix B) have been produced to help answer these questions. The assessment primarily addresses the risks to the environment, as potentially exacerbated by ski area development, without mitigation measures employed.

Assessing risk exacerbated by development depends on knowing some specifics of the proposed development. For example, the risk of constructing ski trails through an area of landslide features depends on the amount of clearing and grading planned. For the purposes of this report, the ski area boundary as proposed in “Alternative 3” from Crested Butte Mountain Resort (2004) has been used as a general guideline. Specific ski trails, roads, utility trenches, areas of snowmaking, and liftlines were not evaluated. Rather, the possible impacts that ski area development activities may have on the stability of each GHU was assessed and presented in Tables 3A through 3F. This information can be used by the proponent to modify its proposal or to guide it in planning or conducting further geological, environmental, and geotechnical studies.

For the risk assessment presented in this report, the probability of reactivation of a landslide decreases with the elapsed time since the last movement. The longer a landslide has been stationary, the more likely it has been subjected to episodes or periods of high precipitation without moving and the less likely it will move in the future. An underlying assumption is that the local climate will remain the same. Other reasons why older landslides are generally more stable than younger ones is that soil densification and weathering increase internal friction and cohesion, vegetative growth reduces water infiltration and binds the soil, and geomorphic processes remove the weight from the head of a slide through erosion. Erosion also develops drainage channels through the often-disrupted surface of the slide, increasing runoff and decreasing the infiltration into the soils.

However, age alone is not an adequate indicator of stability for landslides affected by some aspects inherent in ski area development and operation such as clearing, snowmaking, and grading. Clearing and snowmaking both increase snow accumulation on the slopes and simulate a climate change. Cuts and fills change the distribution of weight and the magnitude of the shear stress within the slide mass. Climatic conditions that did not cause slope movement in the past could cause it in the future because the topography has been modified. Also, in complex slides, movement of one area can decrease the stability of other areas. Movement of a slump mid-slope in a series of older scarps and slump blocks would reduce the resisting force buttressing the currently inactive slumps above and increase the driving force on the slopes below.

For the risk assessment, summarized in Tables 3A through 3F, values of Low (L), Moderate (M), and High (H) risk have been assigned for each of the GHU's for each of the six main ski area modifications: grading and slope shaping, clearing, snowmaking, buried utilities, roads, and liftlines (towers and terminals) and structures. These classifications assume a non-mitigated, natural mountain condition. The generalized ratings of Low, Moderate, and High represent the average impact of a ski area activity on the sensitive slopes within a unit. As such, they may not be representative of the unit as a whole, but rather characterize the potential for movement of the younger features which are more likely to reactivate. These risk values are defined below:

1. A risk value of "Low" means that there is a low probability of slope movement with a specific type of disturbance (or ski area development activity).

2. A risk value of "Moderate" means that there is a moderate probability of slope movement resulting from the activity. If moderate risk is present, one or more additional mitigation measures would be needed to reduce the risk.

3. A risk value of "High" means that there is a high probability of slope movement as a result of the ski area activity. If high risk is present, aggressive and multiple mitigation measures would be necessary. Avoidance of the sensitive areas within these units should be considered first due to a high probability of inducing slope movement. Only if avoidance is not possible or practical, should other mitigation be considered.

Some general guidelines used in this report for assigning a value to the probability of increased or renewed slope movement with disturbance are:

1. For large slides or slide complexes that can reasonably be assumed to be mechanically connected, signs of recent movement at several different locations indicate that the entire slide mass is only marginally stable, at best. Probability of additional movement is medium to high depending on the extent of disturbance and proximity to areas of recent movement.

2. A slide or area of accelerated creep that shows signs of recent movement may experience additional movement due to even a small destabilizing disturbance. Probability of additional movement is high.

3. An old slide that shows no sign of historic (100 year) movement, but also has not been significantly stabilized by geomorphic processes, may be reactivated by increases in snow accumulation, fill material at the head or cuts at the toe of the slope. The greater the disturbance, the greater the likelihood of reactivation. Probability of additional movement is medium to high.

4. An old slide that has been extensively modified by erosion and the development of a drainage system will likely remain stable with minor additional disturbance. The greater

the disturbance, the more likely it will be reactivated. Probability of additional movement is low to medium.

The predicted "severity of impact" (consequences of induced slope movement) are also presented in Tables 3A through 3F. This assessment was not presented in graphic form on maps. Table 4 (Appendix B) is a composite risk and impacts matrix that presents, side by side, the probability of slope movement and the severity of impact on each of the GHU's for each of the six ski area activities evaluated. It is a useful tool to assess the GHU's that are more problematic when disturbed and the activities that potentially induce more slope instability if not mitigated. It also shows the GHU's that are more resilient to disturbance without high risk of slope failure and which activities have the least impacts. It should be kept in mind that, just like with the probability of slope movement, the assessment was for an unmitigated mountain and the severity of impact represents the average impact of a ski area activity on the more sensitive slopes within a unit.

The severity of impact depends on the type of landslides, how extensive an area is affected, amount of lost vegetation and topsoil, increased erosion and downstream sedimentation, and visual impacts. The USFS mandate is to maintain clean water and the productivity of the land. In theory, if any impacts compromise this mandate, then the severity of impact is considered high. However, in practice, some level of resource "damage" can be tolerated if the extent of damage is minimal and the processes are natural and expected to occur. For example, weathering, erosion, and groundwater movement are natural processes that wear on the terrain and contribute to landslides. These are natural processes that produce natural landforms. However, man-made activities can interrupt these processes and either accelerate them (such as cutting a road at the toe of steep or unretained slope) or slow their rate (such as intercepting water above a known landslide). Measures of resource damage, such as the loss of soil productivity, amount of erosion or sedimentation, and volume of material displaced in a landslide, are routinely quantified by the USFS to determine the severity and extent of damage.

Since these measures of resource damage are well-defined, it becomes a matter of what amount of damage is acceptable to the public and the USFS, as a manager of the public lands. In assessing resource damage to other land uses, such as logging, the USFS has determined that if 15% of the "treatment area" is damaged, then this loss would be considered severe or unacceptable. If a similar measure is applied to a ski area, then if a landslide comprises at least 15% of the "treatment area," the resource damage would be considered to be unacceptable. However, the "treatment area" would need to be defined (i.e., is it just the disturbed areas such as ski trails or liftlines or is it the entire permit area?) and the determination would need to be made as to whether the ski area induced the slide or if it was a natural process. Since none of the individual landslides or GHU's in the lower portion of the mountain, which is the area considered to be most active, comprise 15% of the proposed ski area, it would take a more massive, coordinated event involving multiple units to affect a severe impact. Such a failure would be the "fatal flaw," as discussed by Irish (1996) that would determine whether the project was viable or could contribute to large-scale failure of the mountain. Therefore, when evaluating the severity of impact, it is important to consider the "ripple effect" of the movement within any GHU. Some movement could create a more stable condition, while other movement could trigger movement on a larger scale.

Some general guidelines used in this report for assigning a value to the severity of the impact are:

1. There are only likely to be minor increases in the rate and frequency of movement on a recently active landslide, but little or no increase in extent. Some trees may tilt by the renewed movement, but very few fall down. The type of landslide remains the same and the induced slope movement does not reduce the stability of adjacent areas. Severity is low.

2. The type of landslide changes. For example, if in an area of accelerated creep, a shallow translational debris slide or earthflow occurs, the severity would be moderate to high depending on the extent of the landslide. Another example would be if a steep shale scarp failed and turned into a mud or earthflow, then the severity would be high.

3. If a landslide that showed no evidence of historical movement were to be reactivated, the severity would be moderate to high depending on the size of the landslide.

4. If a potentially unstable slope that showed no evidence of landslide movement were to become a landslide, the severity would be moderate to high depending on the size of disturbance and type of slide. A slump or slow moving earthflow would rate lower than a debris flow, rockslide, or fast moving earthflow.

5. If large-scale (>15% of "treatment area") slumping or sliding would occur, then the severity of impact would be high.

Both the probability and severity of additional mass wasting from development of the proposed ski area depend on the effectiveness of the mitigation measures incorporated in the design, implemented during construction, and properly maintained during the life of the project. The extensive areas of historic and older landslides, potentially unstable slopes (including shale scarps), accelerated creep, and topographic restraints make elimination of all risk impractical. In addition, mitigation measures, in themselves, can have adverse environmental impacts, such as altering drainage patterns that may affect wetlands, or adverse visual impacts, such as with some mechanical slope stabilization techniques.

It is important to note that the landslide landforms in the lower southeast portion of the mountain (GHU's #1A, 1B, 2, 4, 5A and 5B), do not stop at the National Forest boundary. They naturally extend beyond (downhill of) the property line, as seen in the Overview Photograph on page 13. Issues such as the potential for slope movement and the accommodation of drainage are real concerns below the National Forest property on the mountain. A central question is whether it is possible that drainage from the mountain could be captured, stored and recirculated for snowmaking, thus reducing the potential for slope movement. However, this could be costly and complex to design, install, and maintain over the life of the project.

Out-of-Forest-boundary impacts were not considered as part of this analysis. However, based on the findings in this study, the majority of the off-site impacts have the potential to be directed towards the southeast to southwest due to the following factors: (1.) the more active landslide landforms continue below National Forest property in the south to southeast portion of the mountain; (2.) the dip of the bedrock is to the southwest; and (3.) the Unnamed Drainage drains the mountain to the southeast towards the sensitive areas.

Finally, landslides on Snodgrass Mountain are a naturally occurring geomorphic process. The point is to design mitigation to reduce the impacts of ski area activities so that these natural processes are not accelerated and that the extent of the landslides are not significantly expanded.

D. Cumulative Impacts Assessment

Each GHU has unique features that may yield a high probability of exacerbating slope stability for a certain activity, but a low probability for adverse impacts from other activities. The same variability can apply to overall risk. That is, there may be high risk for adverse consequences for some development activities within a GHU while risks from other consequences may be benign. Table 5 (below) has been compiled to offer a cumulative assessment of probability of movement and risk as a mountain-wide overview. The values in the table were determined by assigning a value of 10 for high ratings, 5 for moderate, and 0 for low for each activity within a GHU on Tables 3A through 3F. The values for all six ski area activities within each GHU were summed to arrive at the values in Table 4.

Table 5. Cumulative Impacts Assessment per GHU

GHU	Probability of Movement	Severity of Impacts
1A	50	45
1B	35	35
2	40	35
3	40	45
4	35	25
5A	60	60
5B	50	45
6	35	30
7	35	30
8	25	30
9	10	10
10A	15	15
10B	50	50
11	35	45
12	35	30

It can be seen that GHU's #1A, 5A, 5B and 10B have the highest overall probability of movement while GHU's #9 and 10A have the lowest. In regard to risk levels, GHU's #5A and 10B are highest, while units #9 and 10A are again the lowest. As a practical matter, the cumulative ratings can be used as a guide in planning, design, and construction by avoiding the high cumulative score areas, to the extent possible, while concentrating development activities in the low value areas. Likewise, it can be expected that development within units having higher cumulative rating will require more extensive mitigation and greater construction costs than the lower value areas.

This approach assumes somewhat arbitrary values of 10, 5 and 0. A value of 10 is not meant to indicate that its risk is twice as high as a 5. However, it does apply a relative value that can be compared "across the board" since the same levels of risk have the same numeric values. It should be mentioned that this analysis assumes that all activities will occur in all GHU's, which may not be the case. For example, there may be no snowmaking or liftlines on the North Face (GHU #11), which would eliminate the contribution of risk from these two ski area activities to the cumulative impacts. A more sophisticated approach could weight more heavily the activities that directly involve water (i.e., snowmaking, buried waterlines) or activities that change the slope (i.e., grading and slope shaping, roads). This might more accurately assess those activities that have the greatest potential for inducing slope instability. However, there may be no precedence for assigning weights, which would make selection somewhat arbitrary. The value of the simple unweighted method, above, will show the GHU's that have the greatest potential for impacts because a high score indicates moderate to high potential for movement for <u>all</u> ski area activities.

VII. CLOSURE

This document has been prepared based on physical examination of Snodgrass Mountain and observation of its various geologic, geomorphic, and geohydrologic features, as well as review of existing photographs, maps, studies, and reports. It has divided the mountain into discrete Geologic Hazard Units, described probable impacts of the various development activities on these units, and identified mitigation measures that may be employed to reduce the categories of hazard. The information thus present is intended to be used for administrative review of the project and as an aid to the proponent in planning, design, and construction.

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Appendix A

(Maps)

Appendix B

(Tables 3A to 3F and Table 4)

Appendix C

(Ground Photographs)