ENVIRONMENTAL GEOLOGY OF SKI AREA DEVELOPMENTS

by

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ABSTRACT

A model for the environmental geologic analysis of proposed ski areas allows documentation of the interaction between human impacts and the extant geology. This is accomplished by utilizing air photos, topographic maps, field work, and computer analysis and graphics. Once the types and rates of the geologic processes active in the area are determined, the development's effect on these processes can be predicted to determine the geologic impact of the development. An analysis of the existing environment also allows the identification of unsuitable geologic conditions and materials in the development area.

The model is applied to the proposed expansion of the Williams Ski Area on the north side of Bill Williams Mountain, Coconino County, Arizona. The mountain is a composite volcano of late Cenozoic age. Bill Williams Mountain represents a fairly simple setting from an environmental viewpoint. The primary geologic impact of the development is increased soil erosion. Proper construction techniques and seeding of disturbed areas will result in little or no increase in soil erosion. There are no absolute geologic constraints imposed on the project by the extant geology. From a geologic viewpoint, Bill Williams Mountain is a suitable area for the expansion of Williams Ski Area.

CHAPTER I

INTRODUCTION

Purpose and Scope

The use of geologic information in the planning of proposed ski areas has increased in recent years. Undoubtedly this is due to the National Environmental Policy Act (NEPA) of 1969 and its environmental impact statement (EIS) requirement. Unfortunately, a large portion of the geologic investigations of proposed ski areas undertaken are done so only to fulfill the basic legal requirements of the NEPA. Since the NEPA does not specify the specific types of geologic information required in an EIS, their content is, in many cases, lacking a coherent appraisal of the geologic environment and its interaction to the proposed ski area development. The purpose of this thesis is to present and use a model which will maximize the use of geologic information to accomplish the following goals:

1) Evaluation of the geologic factors that affect ski area development.
2) Prediction of how the proposed development will affect the types and rates of geologic processes.
3) Presentation of the information in a variety of formats so as to be useful to the ski area developer, the federal official in charge of reviewing the proposed project, and the geologist and other scientists.

To accomplish the purpose of this thesis, several intimately related topics are discussed. First, there is a discussion of the role of environmental geology and how it is influenced by economic, environmental, and legal factors (Chapter II). Next, factors that influence the selection of criteria used in a geologic analysis of ski areas are ascertained (Chapter III). In other words, the basic conditions under which a model for the geologic analysis of ski areas must function are outlined. This sets the stage for a discussion of the specific types of information needed for the analysis (Chapter IV). Information needed and relevant techniques used to obtain it constitute the model for the geologic analysis of ski area developments. Finally, the model is applied in a study of the proposed expansion of the Williams Ski Area (Chapter V). Thus, this thesis attempts to answer four questions about a geologic analysis of proposed ski areas.

1) What constitutes an adequate geologic analysis?
2) What influences the selection of criteria used in this analysis?
3) How are the criteria used in this analysis?
4) What does a geologic analysis of a specific ski area look like?

Method of Treatment

The geologic analysis of proposed ski areas can be undertaken from two basically different points of view, each having its own limitations. Traditionally, engineering geologic techniques are used to obtain detailed information on material strengths, land surface stability, and general suitability of an area for engineering projects. The application of this technique involves detailed (microscopic) site analysis

through extensive sampling of surface and subsurface materials at the proposed construction site(s). The sampled materials are then subjected to laboratory analysis to determine their composition, engineering characteristics, and suitability for the proposed use. The main limitation of this approach is that it is expensive and time-consuming, particularly if the project area is large or in complex geologic terrain. In contrast to this approach is the type of investigation undertaken in regional planning. Regional planning utilizes a system (macroscopic) approach to determine the suitability of the area for the proposed project (for an example of this method see Turner and Coffman 1973). This approach divides the landscape into "environmental units", each of which has similar characteristics and properties which are related to the proposed use. A limitation of this approach is that the information provided can be too general for a specific engineering design use. A geologic analysis of a proposed ski area can best benefit from a combination of the above-mentioned techniques. Such a combination would maximize the benefits from each technique and at the same time minimize their inherent limitations.

Specific benefits can be obtained from using both microscopic and macroscopic approaches to the geologic environmental analysis of proposed ski area developments. Engineering geologic techniques are utilized at specific structure locations to determine: (1) engineering characteristics of surface and subsurface materials, (2) design criteria necessary for the erection of the structures, and (3) economic costs of building the structure at a specific location. A systems-wide analysis

of the proposed project area would provide the following benefits: (1) identification of areas which present adverse geologic conditions for structure locations (i.e., snow avalanche paths); (2) identification of areas most susceptible to negative geologic impacts (for example, soils with a potential for large increases in erosion if disturbed); and (3) determination of the system-wide impact of the proposed development. Although both of the above-mentioned perspectives are necessary for a complete geologic analysis of proposed ski areas, the primary focus of this paper is on the latter.

In addition to determining geologic criteria that should be used in a geologic analysis of ski areas, this thesis also includes a geologic analysis of the proposed Williams Ski Area expansion. Williams Ski Area is located about three miles south of Williams, Arizona on the north side of Bill Williams Mountain. This case study was included in the thesis to serve as an example of a geologic analysis.

Many traditional geologic methods were used in the Bill Williams Mountain study. Geologic field work has long been the basis from which geologic problems are approached. Information obtained in a field study provides the means by which other types of analysis can be implemented. Aerial photographs and topographic, geologic, and soil maps were utilized prior to the field work. This was done both to provide insight about the study area and to reduce the time spent in the field. Quantitative data were obtained in the field. Surficial particle size, vegetation density, and make-up of the surficial units were measured. Pits were dug to aid in the classification and sampling of the different soil

types. In the laboratory, the soil samples were sieved and studied to further aid in classification.

Some techniques not traditional to geology were also utilized. The most obvious is the application of computer analysis to the study. The University of Arizona's Control Data Corporation Cyber 175 was used to do both statistical and cartographic analysis. FORTRAN programs (written by the author) determined erosion sensitivity of the soils and the soil loss across the area. Other programs were used for terrain analysis and the production of maps. The use of computers allowed the evaluation of their applicability to an environmental geologic analysis of ski area developments.

The author also had an extensive interaction with the developer of the Williams Ski Area. This interaction took two basic forms: (1) input by the developer as to what information is needed by him in terms of geology, and (2) input by the author to identify the geologic conditions that would represent geologic constraints on the development. In particular, the identification of the surficial geologic units involved input from the developer. Because of this interaction, the surficial geologic units mapped on Bill Williams Mountain represent not only geologic but also economic differences (i.e., some units will be less expensive to construct ski trails on than others). This interaction with the developer helped produce a more realistic and useful approach to the environmental geologic analysis of ski areas.

CHAPTER II

THE ROLE OF ENVIRONMENTAL GEOLOGY

An environmental geologic analysis of a proposed ski area can offer several benefits to persons involved in the project. A geologic analysis is termed "environmental" when the dynamic interaction between the proposed project and the extant geology are fully considered. This interaction takes two basic forms: (1) constraints imposed on the project as a result of the existing geologic conditions (geologic constraints), and (2) changes in the types and rates of geologic processes that would occur as a result of the development (geologic impacts). Thus, the application of an environmental geologic analysis to proposed ski areas offers benefits to both the developer and the general public. These benefits include: (1) identification of potential hazards to life, (2) identification of the geologically induced costs, (3) identification of the environmental costs and fulfillment of the National Environmental Policy Act if the proposed project is on public lands, and (4) transmission of the obtained information to all persons involved.

Potential Hazards to Life

A geologic analysis of a proposed ski area enables the recognition of potential geologic hazards to skiers and other land users. Geologic hazards which could pose danger to life and limb include: (1) snow avalanche; (2) landslides; (3) seismic hazards (ground shaking,

ground rupture, and increased landslide potential due to ground shaking); (4) volcanic activity (lava flows, tephra, pyroclastic flows, and mudflows); and (5) floods. These geologic hazards are evaluated in two different ways which are dependent on the size of the area over which the hazard can occur. Some geologic hazards occur over a fairly small area. For example, snow avalanches occur in narrow paths and chutes. The size of the area over which the hazard will occur is small relative to the total development area. Maps can be used to indicate areas with the potential for snow avalanches. Other types of geologic hazards can occur over larger areas. Ground shaking due to seismic activity occurs across the whole development area; in such a case, a map of seismic risk (due to ground shaking) for the area might not impart any additional information over a description (in text) of the area's seismic risk. Thus the geologist can identify (by map and text) and evaluate the geologic hazards in an area that could present danger to human life.

Although all of the above-mentioned geologic hazards could present danger to anyone, some hazards occur more frequently in ski areas. This is especially true of snow avalanche hazards. Gunnar (1974) notes that a large portion of snow avalanche accidents in Switzerland involve skiers. This is probably due to several factors: (1) ski areas usually occur in areas that have large snow accumulations, (2) clearing of vegetation for ski trails increases the potential for snow avalanches, and (3) new snowfall creates both optimum skiing and snow avalanche conditions. In most all ski areas, snow avalanches can present a danger to human life.

Geologically Induced Costs

As part of a geologic analysis of ski areas, the geologist can identify geologically unfavorable sites. Such sites would be avoided and overall construction costs would be minimized. In some instances (such as lift line location), factors other than geologic ones are the primary criteria for structure placement; under these conditions structures could be built in geologically unfavorable areas. In this instance, the role of the geologist would be to identify ways to minimize geologically induced costs due to structure locations in geologically unfavorable areas.

The identification of geologically induced costs primarily benefits the ski area developer. The economic costs induced by the existing geology can be grouped together on the basis of the time span over which they occur. Immediate costs occur during the construction phase of the project. Periodic costs occur relatively regularly throughout the life of the project, after construction has been completed. Aperiodic costs can also occur throughout the life of the project, but much more irregularly than the periodic costs. The precision with which these costs can be estimated decreases from the former to the latter.

Geologically induced immediate costs arise from geologic conditions that increase costs due to necessary engineering procedures. For example, if the main lodge were to be built in an area of swelling soils, engineering procedures would have to be implemented to stabilize the soil and prevent foundation instability. The geologic condition, swelling soils, would cause an increased cost as compared to an area where

the condition did not exist. For any particular geologic condition, there exists a cost level at which correction would become too expensive; structures could not economically be placed at such locations, and the condition would become a geologic constraint. Thus the geologist can identify areas which would cause increased immediate costs or represent geologic constraints and transmit this information to the developer.

Immediate costs are produced by geologic factors that affect the construction costs and times. Although the specific types of geologic factors vary from one area to another, some generalizations can be made. The nature of the bedrock and/or regolith on which structures are built affects the construction costs. Factors that influence soil and regolith suitability include: (1) frost susceptibility, (2) expansion potential, (3) collapse potential, (4) erosion susceptibility, (5) mass movement potential, and (6) material strength. Factors that influence bedrock suitability include: (1) material strength, (2) nature and orientation of discontinuities, (3) ease with which rock can be removed, and (4) mass movement potential. The seismic activity of an area can also affect the construction costs. If the ski area is built in a seismically active area, then the structures must be constructed to withstand the effects produced by ground shaking. This would increase the construction costs.

The action of long-term geologic processes can impose periodic costs throughout the entire life of a ski area. Soil erosion, stream-channel downcutting and/or backfilling, and soil creep are examples of

processes which can impose periodic costs to a ski area. If a ski slope is constructed in such a manner that overland flow of water produces extensive soil erosion, then the ski area would have to develop a drainage system to remove the water from the slope. Aside from the initial cost of building the drainage system, there would also be periodic maintenance costs to keep the system operating at maximum efficiency. Although proper initial construction methods could be used to minimize the overland flow of water, a periodic influx of money would still be needed to keep the level of soil erosion small. In this case, the geologist can reduce costs in two ways. First by communicating to the developer those slope-clearing techniques that would minimize overland flow, and secondly by identifying areas that are sensitive to increased rates of soil erosion.

Geologic hazards can produce aperiodic costs in a ski area development. Geologic hazards are catastrophic processes such as flooding, landslides, volcanic activity, and seismic activity. Due to their aperiodic occurrence, they are usually evaluated in terms of probability or relative risk. Floods, for example, are discussed in terms of their recurrence interval. The recurrence interval for floods of a given discharge is determined by analysis of recorded stream discharges through time. For those streams that do not have a stream gauging record, discharge can also be estimated by using various morphometric characteristics of a stream and its drainage basin (Thomas and Benson 1970). This leads to the estimation of 50 and 100 year flood discharges. A 50 year flood is that magnitude of stream discharge that is equalled or

exceeded once every 50 years on the average. But a flood with a 50 year recurrence interval could occur twice in a given 50 year period; for this reason, it is better to visualize a 50 year flood as that stream discharge that has a 2% probability of occurring in any one year. Thus a given discharge has a certain probability of occurring each year. From this it can be seen that economic costs to a ski area due to geologic hazards can only be approximated.

The main way a geologist can help the developer reduce geologically induced costs is the identification of where adverse geologic conditions occur. This will allow the developer to outline possible alternative locations for engineering structures so as to eliminate or minimize geologically induced costs. This geologic information will be most useful to the developer during the primary planning stages of the ski area. Discussing road construction and landslides, Chandler (1977, p. 157) notes ". . . for planning purposes, it is possible that the early recognition of landslides may reduce construction costs if a road can be routed away from such unstable areas." Periodic and aperiodic long-term costs can also be reduced by inclusion of geologic information in the planning phase of ski area developments.

Environmental Costs

An environmental geologic analysis of ski area developments can aid in the identification of the environmental costs of the development. The identification process involves assessment of the existing character of the physical environment and the types and magnitudes of alteration to that environment that will occur as a result of development.

These preliminary types of work should allow recognition of those geologically unique features that should be preserved. The destruction of geologically unique features by a development is one type of environmental cost. A second and much more common environmental cost is the type and magnitude of alteration that will occur to the environment. The alteration of the environment is the geologic impact of the development.

The recognition of the environmental costs of a development was mandated by Congress with the passage of the National Environmental Policy Act (NEPA) of 1969. The NEPA, Executive Order 11514, and the Council on Environmental Quality's (CEQ) Guidelines of August 1, 1973 (38CFR 20550) ". . . requires that all agencies of the Federal Government prepare detailed environmental impact statements on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment" (Environmental Protection Agency 1975, p. 98). The NEPA is relevant to ski area developments in that a large portion of them occur on federally owned land. In this regard, a geologic analysis of proposed ski areas is necessary for the fulfillment of the NEPA. The intent of the NEPA is to ". . . include in the decision-making process appropriate and careful consideration of all environmental effects of proposed actions by Federal agencies" (Environmental Protection Agency 1975, p. 98). This places environmental costs on an equal standing with economic costs in the feasibility analysis of proposed developments. The consideration of environmental costs is implemented by the environmental impact statement requirement of the NEPA.

The Code of Federal Regulations (Title 40, Chapter I, Part 6, Subpart C) establishes the content of an environmental impact stagement. The body of the EIS should include (Environmental Protection Agency 1975, p. 106-108):

1) "Background and description of the proposed action . . . ."
2) "Alternatives to the proposed action . . . ."
3) "Environmental impacts of the proposed action . . . ."
4) "Adverse impacts which cannot be avoided should the proposal be implemented and steps to minimize harm to the environment . . . ."
5) "Relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity . . . ."
6) "Irreversible and irretrievable committments of resources to the proposed action should it be implemented . . . ."
7) "Problems and objections raised by other Federal, State, and local agencies and by interested persons in the review process."

These legal requirements create a framework around which a model for the geologic analysis of ski areas must be constructed.

Transmission of Geologic Information

A third function of an environmental geologic analysis is to provide the transmission of the obtained geologic information. The specific kinds and quantity of information transmitted varies depending on the type of user. Three basic types of users are considered: (1) geologists and other earth scientists, (2) the planner or federal official

in charge of overseeing the project, and (3) the developer of the project. The actual transmission of information is accomplished by written reports and maps. Due to the areal variation and nature of geologic data, maps are the best suited format for data transmission. Table 1 lists the chief and secondary users of different map types. These users include geologists, developers, and planners. Chief users may utilize the map to produce additional information or to make planning decisions. Thus, the chief user of a map is the person who can obtain the most information from the map. A secondary user can also obtain information from the map, but not to the same extent that the chief user can. For example, the chief user of bedrock and surficial geologic information is the geologist. The geologist uses this information to produce a relative slope stability map. The planner would not be able to create a slope stability map and could not evaluate the slope stability of an area by using the bedrock and/or surficial geologic map. Table 1 indicates that the geologist, developer, and planner are all chief users of the map, showing the proposed and existing facilities. This is not a contradiction to what has just been said; each user is obtaining different, but equally important, and relevant information from the map.

Maps can be classified as to information content and information type. Column 1 of Table 1 classifies maps as to their information content (the information content of a topographic map is the elevation, relative to sea level, of any given point on the map). Column 5 of Table 1 classifies maps as to the information type. Basic information maps contain information which is objective in nature; the map is a

Table 1. Map Information Content and Types of Users.

	User(s) of a Map[1]			Information
	Geologist	Developer	Planner	Type[2]
Proposed and existing facilities	X	X	X	1
Topography	X	X	(X)	1
Bedrock geology	X			1
Surficial geology	X			1
Soil	X			1
Slope	X	X		2
Vegetation cover	X			1
Geologic Hazards				
Snow avalanche	X	X	(X)	3
Mass movement	X	(X)		1
Seismic activity	X	X	(X)	2
Volcanic activity	X	(X)	(X)	3
Flooding	X	X	(X)	3
Percent change in erosion	X	(X)	X	2
Relative slope stability	X	X	(X)	2
Mineral Occurrence	X		X	1

[1] X = chief user(s), (X) = secondary user(s)
[2] 1 = basic information
2 = derivative information
3 = basic and/or derivative information

factual representation of what actually exists. Derivative maps, on the other hand, are more subjective in nature and are derived from basic information. For example, a slope map is a derivative map. Its information is obtained by first using a topographic map to determine the actual slope for specific locations in the area, then areas of similar slope are grouped together. Therefore, the appearance (and information content) of a slope map depends on the method used to obtain the slope from the topographic map. It is important to note from Table 1 that most of the maps applicable to the planner and developer are derivative maps. Because these users have little to no training in geology, the basic information maps are of little use to them; the information presented is too technical. Consequently, one of the roles of the geologist is to present the obtained information in a format which is meaningful and useful to the nongeologist. This is not to imply that basic information maps should be excluded from an EIS; they can be used by other geologists and earth scientists to verify the information presented in the derivative maps.

CHAPTER III

BASIS FOR GEOLOGIC ANALYSIS OF SKI AREAS

The selection of criteria used in a geologic analysis of proposed ski area developments is influenced by several factors. The geographic/climatic requirements necessary for a ski area and its inherent physical characteristics outline a setting in which ski areas occur. This establishes a generalized geographic/geologic setting which is fairly consistent for any ski area studied. A generalized geographic/geologic setting allows the identification of specific geologic processes and hazards which might occur in a proposed ski area and whose effects should be evaluated. The format and information required by an EIS also influence criteria selection. Environmental Impact Statements of proposed ski areas can also outline types and quantities of information used by other workers. A final and often excluded influence on criteria selection is the information needed by the area developer. Consideration of all these factors will aid in the development of an appropriate and useful model for the environmental geologic analysis of ski area developments.

Physical Setting and Characteristics of Ski Areas

The location of ski areas is influenced by several basic requirements which are geographic and climatic in nature. These requirements contain some allowable variance and are what separates poor from

excellent ski areas. Two basic climatic criteria must be met for a ski area to exist at all. There must be sufficient amounts of snow to cover the ground for a portion of the year, although this can be augmented by artificial snow making. The minimum snow depth needed also varies with the physical characteristics of the ground surface (for example, roughness). The length of time that the snow will remain on the ground will be a function of temperature and wind. The daily minimum and maximum temperatures will determine the snow texture, skiability, and longevity. Daily temperature oscillations at or below $0^{o}C$ are optimal.

Geographic criteria are also important in ski area placement. The proposed area must have sufficient relief to enable skiing. The relief present in ski areas in the western United States varies from 244 to 915 m (800 to 3000 ft). Related to relief are the slopes present in the area. There must be present a distribution of slopes to allow use by skiers of all abilities. The following distribution of slope classes is considered optimal for larger ski resorts: (1) 10-25%, novice; (2) 25-40%, intermediate; and (3) over 40%, advanced. The desired distribution of slope classes for a nationally classed resort is novice (15%), intermediate (50%), and advanced (35%) (Flathead National Forest 1976). The distribution of slope classes is also dependent on the skier market that the area hopes to attract. Aspect is also important. The existing aspect(s) will influence the placement of ski trails, with a north or northeast aspect being optimal for snow retention and good snow texture. These geographic criteria show that mountainous regions are needed for ski area locations.

Therefore, geographic/climatic requirements necessitate, in the western United States at least, that ski areas occur in subalpine to alpine zones. These environments present specific geologic processes and hazards which must be considered in evaluating the ski area's interaction with the environment.

The inherent physical characteristics of ski areas also influence their interaction with the environment. Five basic types of facilities are needed to comprise a ski area and its operations: (1) lifts; (2) ski trails; (3) buildings (lodge, garages, and equipment storage; (4) access roads and parking lots; and (5) utilities (gas, electric, water and sewage). Lifts and ski trails are facilities which are unique to ski areas and are discussed in more detail.

Lifts are used to transport the skier up the mountain and onto the ski trails. Lifts can be divided into surface lifts and aerial lifts. The most common types of surface lifts are T-bars, rope tows, and poma or platter lifts. In using a surface lift, the skier is pulled up the lift line with skis on the snow. Aerial lifts (chairlifts, gondolas, and aerial trams) provide seats for the skier who is moved up the mountain in the air. The roughness and surficial characteristics of the ground are more important with surface-type lifts.

The lift cable (or rope) is supported by towers along the length of the lift line with a loading and unloading terminal at each end. Aerial lifts, many times, also have a "midway" terminal for loading and unloading skiers. Slope stability and adequate foundation strengths are essential for the integrity of these lift structures throughout the

project life, but geologic factors are not the sole criteria for lift placement. Topography, slope steepness, and the proximity to ski trail locations are of primary importance in lift placement. Engineering measures must be used if lift placement is in terrain with insufficient slope stability.

The land area used in ski trail construction accounts for a large portion of the total area utilized in the ski area development. The construction of ski trails involves the partial removal of vegetation, boulders, and (in some cases) the reshaping of the ground surface. The combination of these factors cause the construction of ski trails to be a major consideration in determining the impact of the entire development. Of specific importance is the effect of the ski trails on slope stability, soil erosion, and snow avalanche hazard.

Geologic Setting of Ski Areas

Although the geologic setting will vary from one ski area to another, generalizations can be made as to the types of geologic processes active and to the geologic hazards present in mountain alpine environments. The geologic setting of an area is the result of both past and present processes acting on the area. The evaluation of an area's geologic setting involves determining the geologic processes that were active in the past. This will then allow the identification of geologic hazards produced by these processes.

Active Geologic Processes

The dominant geologic processes active in mountain alpine environments include: (1) mass movement, (2) mechanical weathering, (3) chemical weathering, (4) fluvial activity, and (5) glacial activity. Mass movement is identified by several workers as being responsible for a large portion of the denudation and movement on mountain slopes (Benedict 1970, Hewitt 1972; Swanson and Dyrness 1975). The specific types of mass movement range from catastrophic, fast-acting landslides to slower acting frost creep. The nature of slope movements active at any locality is strongly influenced by rock type, structure, topography, and climate. It is important to note the locations and types of mass movement present in an area in the evaluation of the geologic setting of that area.

Hewitt (1972, p. 25) notes that mechanical weathering is more important in the mountains than in lower lying areas. A large amount of mechanical weathering on cold mountain slopes is accomplished by two related processes--changes in water volume due to freezing and thawing, and formation of segregated ice (French 1976). These processes produce frost heaving, frost wedging, pipkrake, frost mounds, and frost sorting (Washburn 1973, French 1976). The primary importance of mechanical weathering is that it produces the loose broken material which can then undergo mass movement. Thus the identification of areas experiencing extensive frost action is important to recognizing areas subject to slope instability.

Rapp's (1960) work in Karkevagge Scandinavia emphasized the importance of solution in cold environments. He determined that the

transportation of dissolved salts was the most important mass transfer process on mountain slopes. This is not obvious from a visual examination of an area, in that the physical effects of mechanical weathering are often more noticeable. Even though the effects of chemical weathering probably are significant, they are difficult to quantify mostly because insufficient work has been done on this subject. The best a geologist can do is to provide some type of qualitative information on the relative susceptibility of materials to chemical breakdown.

The operation of the fluvial systems can also be affected by a development. Road and ski trail construction (with their decrease in vegetation density and reshaping of the land surface) will tend to increase the water runoff from slopes, peak discharge of streams, and sediment yield. The response of the fluvial system to these changes can be complex. Portions of the stream could downcut while other parts could backfill. It is also possible that no changes could occur.

The stream systems flood volumes and recurrence intervals should also be considered. In ski areas most buildings are located at or near the valley bottoms and would be subject to floods. An estimation of the flood recurrence interval and water volumes are crucial in determining the safety and structural requirements for these buildings.

Past Geologic Processes

A basic understanding of the geomorphic history of an area is relevant to the understanding of the current geologic setting. Aside from active geologic processes, past processes active in the area must also be studied. These "legacies from the past" could have a great

effect on the current slope morphology and stability of an area. Evidence indicating past processes which could influence current slope suitability and stability include: (1) fossil solifluction forms; (2) preexisting landslides, (3) oversteepened valley sides, and (4) deep weathering (Cooke and Doornkamp 1974). Several workers have noted that areas which have undergone mass movement in the past are more susceptible to present-day slope failure (Cooke and Doornkamp 1974, Nilsen and Turner 1975). Oversteepened valley sides also indicate areas which are more susceptible to slope failure. Deep weathering creates a regolith with decreased internal strength which would be prone to shallow slides.

Geologic Hazards

The interaction between the past and present geologic processes active in an area determines the geologic hazards and constraints existing in that area. The previous discussion briefly outlines the types of geologic processes that would be expected to occur, or have occurred, in mountain alpine environments. This allows an identification of the types of geologic hazards that would be expected to exist. Local geologic and climatic conditions also influence the types of hazards present in an area. Six basic geologic hazards should be considered in evaluating the geologic setting of an area: (1) snow avalanche, (2) mass movement, (3) seismic activity and ground rupture due to faulting, (4) volcanic activity, (5) foundation stability, and (6) flooding. These hazards, which are mostly catastrophic in nature, will greatly affect the safety and feasibility of a proposed ski area.

Geologic Analysis by Other Workers

An examination of the environmental impact statements for proposed ski areas indicates the types of criteria used by other workers. Five environmental impact statements for ski areas were reviewed to determine the geologic criteria used in their preparation. The impact statements studied were the Big Mountain Ski Resort Master Plan Final EIS (Flathead National Forest 1976), the Sierra Ski Ranch Expansion Draft EIS (Eldorado National Forest 1977), the Red River Ski Area Expansion Proposal Final EIS (Carson National Forest 1977), the Future Development Mt. Hood Meadows Ski Area Draft EIS (Mt. Hood National Forest 1977), and the Mount Hebgen Management Alternatives Final EIS (Gallatin National Forest 1976). The quality and quantity of geologic information included varies greatly among the five studies. Table 2 lists various types of geologically related information and which impact statements discussed them.

The five impact statements studied show definite similarities in the types of geologic information discussed. Soil information is included in all of the five. In most cases, the soils are classified by an agricultural soils classification as used by the U. S. Department of Agriculture. Then the information is commonly presented in tabular form. One outstanding exception to this is the Mt. Hood Meadows EIS. In this EIS the soils are classified into four categories based on the soils limitations for use in the development. The criteria used in this classification are based on the soils potential for erosion and landslides. The classification categories are user-oriented and include:

Table 2. Information Content of Five Ski Area Environmental Impact Statements.

Information	Mount Hebgen EIS	Big Mountain Ski Resort EIS	Mt. Hood Meadows EIS	Red River Ski Area EIS	Sierra Ski Ranch EIS
Proposed and Existing Facilities	T/M[1]	M	T/M	T/M	T
Geologic History and Geologic Setting	T	T	T		T
Hydrology	T		T/M	T	T
Topography	T/M	M	M	M	M
Bedrock Geology	M			M	
Surficial Geology		T			
Soils	T	T	T/M	T	T/M
Slope			T	M	T
Vegetation Cover	T		T/M		
Geologic Hazards					
Snow Avalanche			T/M		T
Mass Movement			T		T
Seismic Activity		T	T/M		T
Volcanic Activity			T		
Flooding			T		
Soil Erosion	T	T	T	T	
Slope Stability					

[1] T = discussed in the text
M = presented by map

(1) critical (unstable landslide prone soils), (2) severe (soils which require extreme care in planning and management), (3) moderate (soils which require careful management), and (4) slight (few limitations, if any). This classification scheme emphasizes the limitation imposed by the soils of an area. The classification is nontechnical so that it can be used by the developer and planner. This approach is good in that it allows any reader to evaluate the proposed development in light of the existing soil conditions. Information of this type is not easily obtainable from soil maps using an agricultural soils classification unless the reader is knowledgeable in this soil classification system.

Several other types of geologically related information are also discussed in the five impact statements studied. Information discussed includes hydrology, geologic setting and history, seismic activity, and erosion. This information is presented in a qualitative rather than a quantitative manner. For example, soil erosion is discussed in four of the five impact statements. Increased erosion during development construction is cited as the major factor contributing to soil loss. The magnitude of increased soil loss is not indicated. Only one EIS makes use of some type of soil loss equation (Sierra Ski Ranch EIS); the soil loss equation was Anderson's (1969) revision of Musgrave's (1947) factorial approach to the quantification of soil loss.

Geologic information is presented in the impact statements by text, tables, and maps. Table 2 shows the various types of maps used in the five impact statements. Table 1 lists the information types of these maps. A majority of the maps used in the statements are of the basic

information type. Derivative maps are easier for nonearth scientists to use than are the basic information maps. A good example of a derivative map is the soils map (previously discussed) in the Mt. Hood Meadows EIS. To summarize, there is no apparent standard for the geologic information in the impact statements studied. The magnitude of impacts is expressed in qualitative rather than quantitative terms. A majority of the geologic information contained in the impact statements is more oriented toward the geologist than to the developer or planner.

Other Criteria for a Geologic Analysis

The information needed for a geologic analysis of ski areas is also determined by the legal requirements of the NEPA and the needs of the developer. Chapter II discusses some of the information needed by the ski area developer, such as geologically induced costs and geologic constraints. The basic data needed to supply this information include: (1) suitability and limitations of each surficial unit for lift and ski trail construction, (2) foundation stability in areas of lifts and buildings, (3) location of areas subject to adverse impacts, (4) mitigation guidelines to minimize adverse impacts, and (5) location of areas subject to geologic hazards. In other words, an evaluation of how the extant geology will increase costs and the identification of areas unsuitable (due to adverse impacts or high costs) for use in the development.

The information needed for a geologic analysis is also determined by the legal requirements of the NEPA. Basically, the NEPA requires two kinds of information--documentation of the physical

environment and identification of the adverse environmental impacts of the proposed development. The documentation of the physical environment should include a discussion of the geologic history and setting of the area. The purpose of this is two-fold--to help identify the inherent value of the area and to establish a "base line" from which changes in the environment due to development can be predicted. The identification of adverse environmental impacts involves the prediction of how the rates and types of geologic processes are affected by the development. Specific topics that should be discussed include soil erosion, slope stability, and changes in the mode of operation of the fluvial system.

CHAPTER IV

GEOLOGIC ANALYSIS OF SKI AREA DEVELOPMENTS

The purpose of this chapter is to provide information on techniques, methods, and literature relevant to a geologic analysis of ski areas. The first section of this chapter deals with office and field techniques used to analyze the study area. The second section outlines what information is needed to document the geologic environment. Section three outlines environmental impacts that should be discussed and relevant techniques. The final section discusses the identification of geologic constraints to the project. This chapter outlines a model or framework to be used in the geologic analysis of ski areas.

Methods and Procedures

Like many other geologically oriented studies, the geologic analysis of ski areas can be accomplished by both office and field analysis. To save time and increase efficiency in the field, some amount of office work is essential before the field season begins. Many times field work will be used to supplement, quantify, and verify the work done in the office. The types of office work discussed include remote sensing and computer analysis.

Remote Sensing

The use of remote sensing is essential to this type of study. Air photo coverage is now available for most of the United States.

Information on photo coverage for a specific area can be obtained from the Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, South Dakota. The user supplies EROS with the latitude and longitude of the study area and EROS returns a computer listing of coverage available for the area. If the study area is on government owned land, there is also the possibility that the organization in charge of the land (Forest Service, Bureau of Land Management, State, etc.) will also have their own air photo coverage. Although black and white photos are usable, color photos provide much more information to the geologist. Existing literature provides detailed information on the applications of remote sensing to geology (Holden 1968, Webster and Beckett 1970, Uhrin 1973, Estes and Senger 1974, Reeves 1975, Leberl 1976, Schanda 1976, Verstappen 1977).

Aerial photos of the study area should be utilized before the actual field work begins. The photos can be used to locate and map surficial geology, structure, vegetation (type and density), soils, landslides, and snow avalanche paths. Color, tone, and texture are the primary criteria used to delineate surficial, soil, and vegetative units. These criteria, along with morphology, are useful in identifying landslide and snow avalanche paths. The advantage in using air photos is that they allow a large-scale appraisal of the area that would be difficult, if not impossible, from the ground.

Features and units identified on air photos should be evaluated on the ground by actual field work. Field studies provide a "ground truth" to previous air photo interpretation. In many cases, units

delineated on air photos represent obvious differences in the field. On the other hand, air photo delineated units may not show any difference on the ground.

In some cases, air photos can be used directly as a base for field mapping. This is especially true when mapping is done at large scales (larger than 1:12,000). For example, to produce a topographic map at the scale of 1:6000 would require a two-fold enlargement of a 7½' topographic map. When a topographic map is enlarged, the accurate identification of a location in the field may be difficult. Air photos, on the other hand, allow very accurate location in the field. There are two limitations to mapping directly on air photos: (1) in areas of heavy vegetative cover (i.e., dense forests) it is difficult to determine precise locations; and (2) in areas of high relief (especially on one photo sheet) the photo scale is not constant. The second limitation can be overcome by the use of radial plotting methods when transferring air photo data to a planimetric base map (Compton 1962).

Computer Analysis

The application of computers to geology is a relatively recent development. The advantages of utilizing computer analysis are reduced costs and time. High-speed digital computers can rapidly evaluate information that would very time-consuming to evaluate by traditional methods. Along with performing repetitive mathematical calculations, computers can also graphically display information. Computer graphics can be used to produce graphs, tables, and maps. The production of computer maps is very useful in environmental geology. Basic data

(surficial and bedrock geology, soils, slope, vegetation, structure locations) can be related in various ways and maps produced. (For example, soils, surficial geology, and vegetation density are used to produce a map of the erosion susceptibility of soils.)

There are many existing computer programs that can be used in geologic analysis of areas. Two, in particular, are very useful for the geologic analysis of ski area developments. They are TOPO III (Grender 1976) and SYMAP (Version 5.2, produced by the Harvard University Laboratory for Computer Graphics and Spatial Analysis). TOPO III is a terrain analysis program and SYMAP is a mapping program.

TOPO III is a terrain analysis program written in FORTRAN. A current version has been published and documented by G. C. Grender (1976). Elevations are the basic input data used by TOPO III. The elevations are obtained by gridding a topographic map of the study area with equally spaced lines. The elevation at each line intersection is recorded and used as input to the program. From these elevations, TOPO III (Grender 1976, p. 195) can produce information such as:

> Size-frequency distributions of subarrays comprising contiguous points that have the same basic topographic 'shape' (slope, ridge, valley, knob, sink, or saddle).
>
> Distributions of maximum and average slopes, with percentages and cumulative percentages.
>
> Frequency distributions of the six basic topographic shapes, and a printed map showing the shape at each point in the operating array.
>
> List of terrain parameters for each point in the operating array: elevation, maximum and average slope and relief at the given scale, azimuth of maximum slope, and topographic shape.

Printed symbolic slope map indicating the category of maximum slope and its azimuth unit at each point in the operating array.

The program was modified by the author to also determine the average and maximum convexity and concavity for each point in the operating array. From a minimum amount of input data, TOPO III can provide a large amount of useful information to the user.

In its current form, TOPO III has two main drawbacks. The "symbolic slope" and "topographic shape maps" produced by TOPO III have two different horizontal scales. Each print character on the map represents a grid intersection, with the grid points spaced equidistant from each other. But the computer line printer prints characters with a 10/inch column spacing and 8/inch or 6/inch row spacing. The TOPO III map is distorted in the printing of the map. A second problem with the program is that it requires a large amount of computer memory (core). This is partially due to how the program handles the elevation array. The bigger the elevation array size, the more memory the program needs to run. If the study area is large it can be subdivided into smaller units and the memory requirements of the program will be lowered.

Despite its drawbacks, TOPO III can be effectively utilized in the production of maps with the same horizontal scale in both directions. This is accomplished by using the "list of terrain parameters" output by TOPO III as data input to a mapping program, such as SYMAP. The parameter list output by TOPO III contains (for each point in the operating array): (1) elevation (the user's input), (2) average and maximum relief, (3) average and maximum slope (expressed as a tangent; multiplied

multiplied by 100 it equals percent slope), (4) aspect (azimuth of maximum slope), (5) topographic shape, and (6) average and maximum convexity and concavity (the derivative of the slope; i.e., rate of change of slope). Each of these parameters can be used as data for display by a map.

The SYMAP computer mapping program can be used to display the TOPO III produced data. SYMAP is made to accommodate the different character spacing of a computer line printer. The user can specify to the program the print spacing that will be used. SYMAP will also produce maps to any user-specified scale. The program allows many options: (1) production of various types of maps; (2) production of maps with irregular outlines; (3) user input of cultural and other information (roads, buildings, section lines, streams, lift lines, etc.); and (4) some user control of the interpolation algorithm. (For a fuller discussion of the SYMAP program, see Eougenik and Sheehan, 1975.)

SYMAP can produce several types of maps, such as conformant, proximal, contour, and trend surface. In a conformant map the data are grouped into zones. The differences between the zones are usually qualitative rather than quantitative. Conformant maps are used in displaying surficial geology, bedrock geology, soil, and vegetation data. To produce a conformant map the user inputs the boundaries of the different zones into SYMAP. The three other types of maps use data values as input, then SYMAP computes the values for those areas where data do not exist. In the production of a proximal map, values are assigned to points by using the value of the nearest data point. This is useful for

displaying slope data. Contour maps are also produced by SYMAP; they are the default map type. The basic SYMAP algorithm ". . . can compute a continuously differentiable, regularly spaced data surface from a series of irregularly spaced input values . . .. The algorithm uses a weighted average of known data values, based on an inverse distance model, with correction for other characteristics of the data surface such as special configuration of the data points" (Schmidt and Zafft 1975, p. 234). SYMAP can also produce trend surface and residual surface maps from one to sixth order. SYMAP offers a wide variety of choices in the method of analysis and display of input data; this makes it very applicable to geologic mapping.

The use of computers for mapping requires a nontraditional concept of spatial data. The area to be mapped is treated as if it were a series of contiguous, separate smaller areas. On the finished map, each area is represented as one print character. The actual area represented by the character is dependent upon the map scale. For example, a map scale of 1:6000 would cause each print character to represent 290 sq m (3125 sq ft). There are several ramifications as a result of this concept: (1) the scale of base map from which input values are obtained determines how accurately the computer map portrays the actual data (the larger the scale the more accurate the computer map), (2) the scale of the computer map produced also affects the accuracy, (3) the area represented by a print character is the smallest planning unit. Various different types of information are known about each subarea (i.e., slope, surficial geology, soil characteristics), and this

information can be used to make planning decisions. For example, to determine the erosion sensitivity of the soils in an area, slope vegetation density, and soil characteristics for each subarea are used in a soil loss equation. This indicates that the selection of scale is an important step in computer mapping. The chosen scale is dependent on the inherent complexity of the area and the amount of detail needed in the finished map. Computer costs are directly proportional to the detail as well as the size of a map produced. These factors must be weighed to determine an appropriate map scale.

Documentation of the Geologic Environment

A necessity in any geologic analysis is the identification and documentation of the existing geologic and geographic characteristics of the area. Seven separate characteristics of an area need to be investigated and documented. These are topography, slope, bedrock geology, surficial geology, vegetation, soils, and geologic hazards. For most of these characteristics maps are the best suited method to display the obtained information. Each of these characteristics will be discussed along with techniques used to identify, evaluate, and document them.

Topography

Topographic maps are published for much of the United States by the U. S. Geological Survey. For detailed mapping, as is needed in ski area analysis, the published map should be enlarged to a scale of 1:12,000 or larger. Accuracy of the topographic map is important when data are extracted from it for computer analysis. The enlarged

topographic map can be compared to air photos to ensure that stream course location and cultural information are accurate and complete. The topographic map is then gridded and elevations recorded at grid points and used as input data for TOPO III. A computer map should then be made using the input elevations; this is then compared with the topographic base map. The match-up between the two topographic maps is a check to determine if a fine enough grid spacing was used. In the author's study of Bill Williams Mountain, the topographic base map scale was 1:6000 (enlarged from a 7½' U. S. Geological Survey map) and a grid spacing of .635 cm (.25 in) was used. Over 2000 elevations were punched on cards for an input data to TOPO III. This combination provided sufficient detail in representing the elevation data.

Slope

The slope of a point is defined by a plane tangential to the land surface at that point. This plane has both a gradient (inclination to the horizontal) and an aspect (i.e., degrees from north). The slope is actually the first derivative of elevation--the rate of change of elevation (Strahler 1956, Evans 1972). This is true only if the slope is determined as a tangent (Strahler 1956). When the tangent of the slope is contoured, the resulting map is an isoclinal or isotangent map. Slope can also be displayed as the size of the gradient angle, in which case an isosinal map is produced. Isosinal maps are actually shear stress intensity maps which show the portion of the total gravitational force acting to produce downslope movement (Strahler 1956). Isoclinal

maps are the most useful for this type of geologic study. TOPO III computes the slope from the elevation data as the tangent of the slope angle (Figures 1 and 2). An important consideration in producing slope maps is that the slope should be measured over as small an area as possible (Evans 1972).

Noncomputer methods can also be utilized to produce slope maps. Verstappen (1977) is an excellent reference for noncomputer techniques. These methods use the density of contour line spacing to manually determine slope. Evans (1972, p. 40-41) notes that "Where automation permits finer sampling of slope, the matrix-based method is clearly superior to the contour density method." A major advantage of using the computer method is that maps using different slope categories are easily produced. Using the contour method, a new map would have to be made by hand for each set of slope categories employed.

TOPO III determines the average and maximum slope for each point in the operating array. The program operates by making pairwise comparisons of point elevations around the point for which the slope is being determined. The maximum slope is the largest value of the comparisons around each point. The average slope is an average of all the pairwise comparisons for a point. The maximum slope seems to more accurately portray the "real" slope of the area.

Once the slope for each array point is determined, it can be displayed in various manners. The developer is interested in the distribution of slopes of different skier classes. Useful skier class slope categories are 0-20%, novice; 20-45%, intermediate; and over 45%,

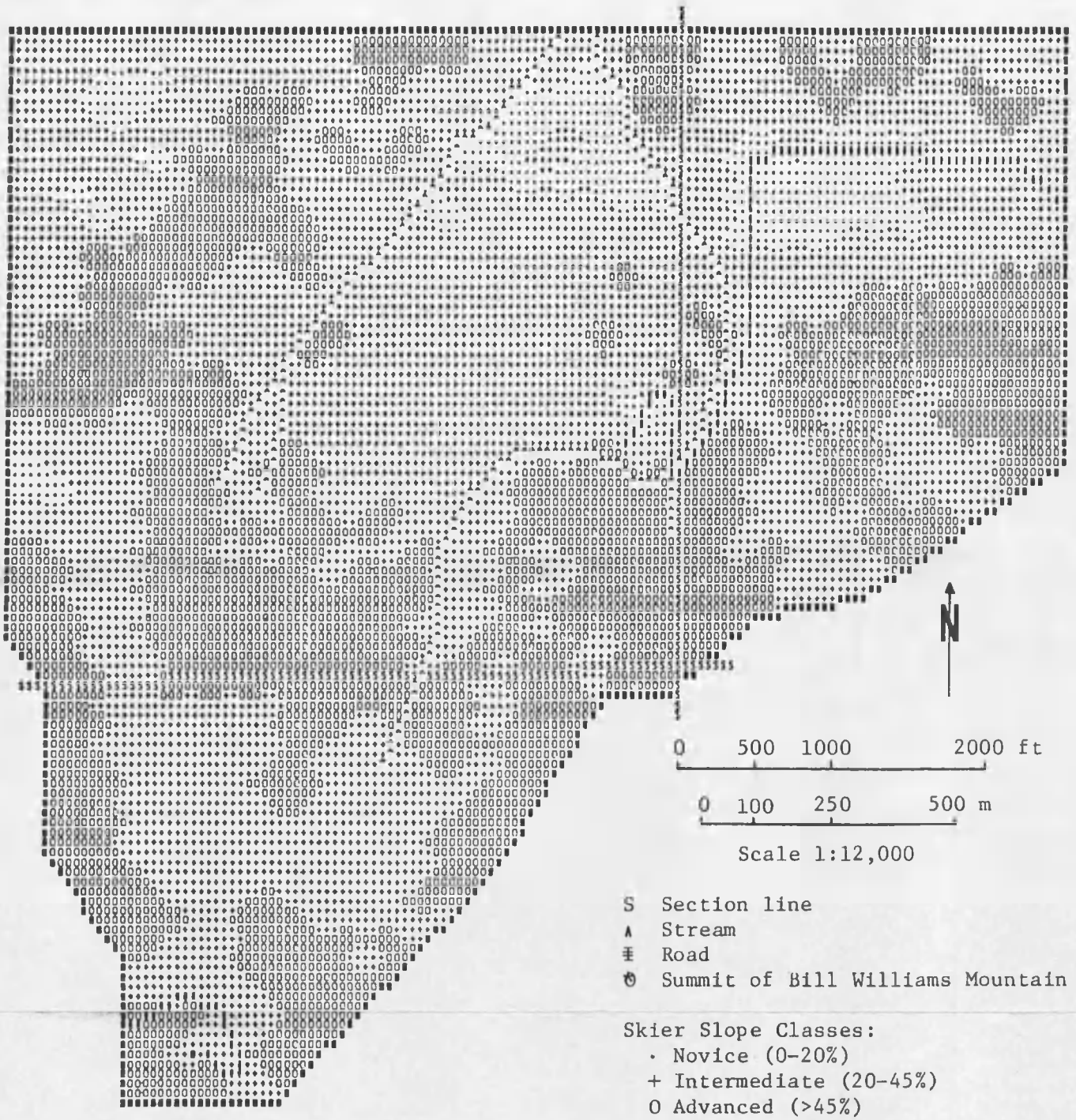

Figure 1. Skier Class Slope Map.

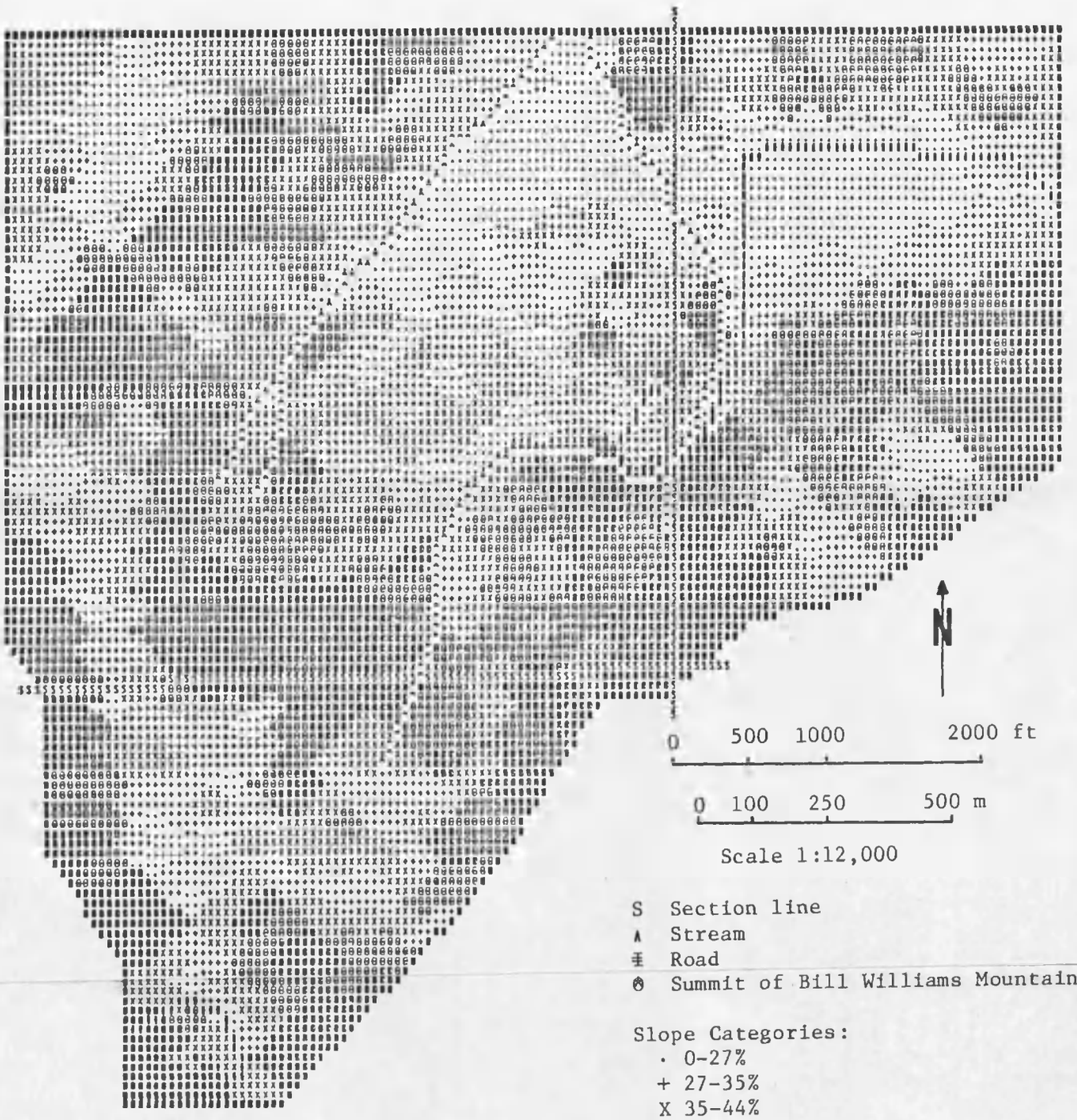

Figure 2. Slope by Quantiles.

advanced (Eldorado National Forest 1977). For an example of a skier class slope map, see Figure 1. Different slope categories are used to estimate snow avalanche hazard. Mellor (1968) has linked the following slope classes to show avalanche hazard in the mountains of North America: (1) 0-27%, virtually no sliding; (2) 27-47%, sliding rare; (3) 47-70%, occasional sliding; (4) 70-173%, frequent sliding; and (5) above 173%, constant sloughing. Categories 3 and 4 represent the greatest potential for snow avalanche. A third manner of displaying the slope values is by quantiles. Using quantiles, the data are grouped into categories which contain an equal number of data values. Therefore, if 5 quantiles are used, the third quantile contains the mean and mode values. Quantiles are useful because they cause the data to be grouped in terms of the distribution and range of all the values. For an example of a slope by quantile map, see Figure 2.

Bedrock Geology

The bedrock geology of an area may or may not be important in determining the suitability of the area for development. "Two points will be immediately obvious to the reader: first, that a simple geologic classification in terms of igneous, sedimentary, metamorphic, and second, that a strong dependence upon the intrinsic strength of constituent elements, are factors that may well be irrelevant in a description of the engineering strength of rock masses" (Attewell and Farmer 1976, p. 730). Bedrock geologic maps typically differentiate units on the basis of age, genesis, and lithology. These criteria do not necessarily determine the engineering characteristics of the rocks. The possibility

also exists that the bedrock is completely covered by surficial units which are unrelated genetically to it. In this case, the engineering properties of the bedrock would bear no relationship to the engineering properties of the surficial units. On the other hand, the weathering and physical characteristics of the bedrock could be intimately related to the engineering properties of the surficial material if the surficial material is a weathering product of the bedrock. In terms of soil erosion, it is not the rock type but rather the weathering products of the rock type that are most commonly eroded. The relationship between bedrock and surficial material also varies from area to area; their relationship must be evaluated for the whole study area.

In many cases, an engineering geologic map is more suitable than a bedrock map in determining the suitability of an area. Criteria used to differentiate engineering geologic units are based on the physical characteristics of the material. Physical properties which are related to the engineering properties of rock are strength of the rock material, water content, macro-structure, and elevation of the groundwater table (Zaruba and Mencl 1969). The specific information needed for a description of the engineering geologic characteristics of a unit include color, grain size, texture, structure, discontinuities within the rock, weathered state, alteration state, strength properties, permeability, orientation of structures and discontinuities, and information on the weathering profile. Studying the discontinuities is important in predicting the stability of the bedrock (Cooke and Doornkamp 1974). Discontinuities are produced by jointing, stratification, flow banding,

and faulting. If bedrock is exposed at proposed structure locations, information about discontinuities is even more important. This information should include orientation (strike and dip) and its relationship to the ground surface, spacing, continuity, thickness and nature of gouge materials, weathering conditions, and surface roughness (Taylor 1969, Cooke and Doornkamp 1974, Attewell and Farmer 1976).

Whatever name (geologic or engineering) is applied to the final map is not important. It is important that the units be differentiated on the basis of engineering characteristics related to the proposed use and that the physical properties of the units be fairly uniform throughout.

Surficial Geology

An understanding of the surficial geology will reveal information on the recent geologic history, current geologic setting, groundwater, construction materials, and engineering characteristics of the area (Compton 1962). Surficial units can be differentiated on the same basis as bedrock units--lithology, age, and genesis. Surficial units identified by genetic relationships (i.e., alluvium, colluvium, and talus) will also have engineering differences. Age is relevant to the engineering properties of a unit. The extent of weathering and thickness of the weathering profile, which for a specific area are dependent on age, affect the surface and subsurface strength properties of the materials. Surficial deposits are intimately related to landforms. Landforms, in turn, are produced by specific processes with discernible

rates. Some types of geologic hazards can be related to landforms. Snow avalanche, solifluction, and mass movement produce distinctive morphologies and landforms. Understanding processes and rates active in an area provides a basis for determining engineering suitability of the area. (For an example of a surficial geologic map, see Figure 3.)

Vegetation

Vegetation type, distribution, and density are important in the geologic evaluation of an area. These vegetation parameters can be used to determine fire scars, snow avalanche scars, timbering scars, or recent soil movement. Vegetation can also be used in dating periods of mass movement. "The state of tree growth is indicative of the age of recent sliding movements. Trees on unstable ground tilted downslope, tend to return to a vertical position during the period of rest so that the trunks become conspicuously bent from the younger, vertically growing trunk-segments, the date of the last sliding movement can be inferred" (Zaruba and Mencl 1969, p. 100). The deflection of roots of annual plants could be used to estimate the amount of soil creep.

Vegetation can be quantitatively related to rates of surficial processes. Vegetation density is used in equations to predict annual soil loss. Owens (1969), in a study in the Southern Alps of New Zealand, found a relationship between average soil movement and the amount of bare area. The effects of plants on the soil to reduce mass movement and erosion are: (1) roots of plants tend to stabilize the ground, (2) vegetative cover reduces raindrop impact, and (3) vegetative cover provides frost protection for the ground (Rapp 1960). Vegetation density

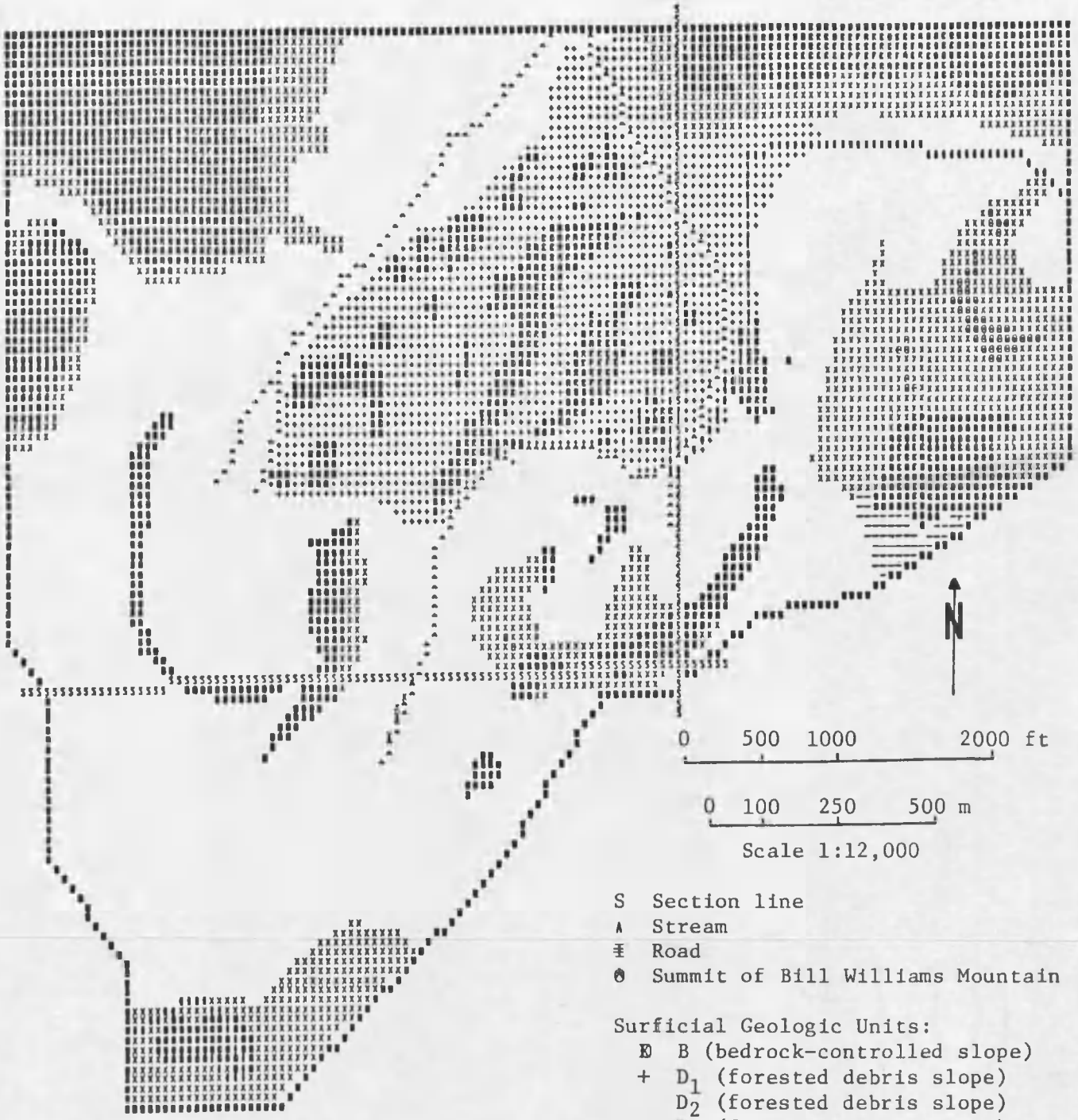

Figure 3. Surficial Geology.

can be measured in the field or from air photos, depending on the type of plants present. Vegetative density measurements are discussed by Evans and Love (1957) and Branson and Owen (1970).

Soil

Soil characteristics are relevant to a geologic analysis of an area. Most available soil maps are based on the agricultural soil classification system as used by the U. S. Department of Agriculture. This classification is of limited value for engineering purposes. "From the engineering point of view, information of this type [agriculture soil classifications] is qualitative rather than quantitative, but if properly evaluated it can often be used to advantage in the reconnaissance stage and in planning subsurface explorations for dams and other structures" (U. S. Department of the Interior 1974, p. 83-84). The use of Unified Soil Classification System is preferred for applications to engineering projects. Soils classified by this system can be identified as to specific physical properties such as permeability, compactibility, shear strength, frost action potential, and expansion potential (Van Horn 1968).

Of all the physical attributes of soils, grain size distribution is of particular importance. The amount of the soil fraction finer than 0.02 mm is directly proportional to the rate of frost heaving and related to the susceptibility of the soil to ice lens formation (Gillott 1968, Corte 1969). Freeze-thaw in soils is thought to be a major cause of soil creep (Owens 1969). Creep is thought to be a precursor to more catastrophic slope failures (Gray 1977). Washburn (1973) indicates that

solifluction is also strongly influenced by grain size. Thus grain size distribution is an important factor in the determination of the frost heaving potential and slope stability of soils.

Soil type distribution is most easily presented by maps, although tables are also useful for the efficient description of soil characteristics. Maps showing soil units delineated by the U. S. Department of Agriculture or the Unified Soil Classification System are of little use to nongeologists. The soils should be classified in a user-oriented manner. The previously mentioned classification used in the Mt. Hood Meadows EIS is an excellent example. The soils are classified into categories related to their limitations to the proposed development. Another classification scheme would group soils by their sensitivity to erosion (discussed later in this chapter).

In some areas the bedrock geology, surficial geology, vegetation, and soils are intimately related. The soil type can be directly related to the bedrock from which it forms. Soils are also related to surficial units and their landforms. It is possible that several different types of units (surficial, bedrock, and vegetation) have the same boundaries. If this occurs, it is unnecessary to produce all the separate maps as long as the relevant characteristics of all the units can be shown on one map.

Geologic Hazards

Several different types of processes are grouped under the heading of geologic hazards. The one thing they have in common is they are generally fast-acting and catastrophic in nature. This discussion of

geologic hazards includes such things as snow avalanche, mass movement, seismic activity, volcanic activity, and flooding.

Snow Avalanche. Snow avalanches are particularly important in the geologic hazard analysis of ski areas. A large portion of avalanche accidents in Switzerland involve skiers (Gunnar 1974). Snow avalanches can be classified as to magnitude, nature of snow, morphology of their paths, type of rupture, type of movement, and triggering mechanisms (Mellor 1968, Gardner 1970). The morphology of the avalanche path is easily identified (from air photos and in the field) and useful for the delineation of avalanche zones. The two basic types of avalanche paths are open, flat paths and channeled paths (Mellor 1968). Once identified, avalanche terrain is classified as to the existing hazard. The U. S. Department of Agriculture (1961) uses four classes of avalanche hazard:

1) minimum hazard (indicates practical absence of hazard;
2) low intermittent hazard (indicates occasional exposure to avalanches of dangerous size;
3) high intermittent hazard (indicates areas frequently, every major storm, subject to avalanches of dangerous size;
4) high intermittent hazard, not controlled (indicates highly hazardous areas which are not feasible to control

(U. S. Department of Agriculture 1961). The U.S.D.A. (1961) also outlines four steps to avalanche safety planning: (1) terrain analysis, (2) climate and weather analysis, (3) hazard classification, and (4) identify operations procedures.

Avalanche hazard areas are relatively easily identified by geomorphic evidence. The terrain is analyzed to find locations of slide paths and depositional areas. The presence of an avalanche depositional area is indicated by avalanche boulder tongues (Potter 1969, Gardner 1970). These boulder tongues are transitional in form between talus cones and alluvial fans (Gardner 1970). Potter (1969) states that avalanche debris tails are also indicative of depositional areas, although these features are usually only present above treeline. Schaerer (1972) identified three characteristic types of avalanche terrain--cliffs; gullies, usually V-shaped with numerous branches and no defined starting zone; and lee slopes of mountain ridges. The basic terrain characteristics which are relevant to avalanche occurrence and hazard include slope angle, shape of track, roughness of track, vegetative cover (especially height), and exposure to wind and sun (Schaerer 1972). The use of geomorphic evidence allows the delineation of both avalanche paths and their depositional areas.

Vegetation is also useful in avalanche studies. "The position of treeline is extremely important for the avalanche study. Avalanche starting zones are located primarily above treeline, while the track and runout zones generally lie below it. Thus the avalanche impact on the vegetation delineates all but the most infrequently active avalanche paths in a most dramatic manner" (Armstrong and Ives 1976, p. 4). Dendrologic information can be used to infer avalanche frequency (Potter 1969). The criteria used by Potter (1969, p. 141) to determine avalanche frequency were ". . . datable scars on the trees . . . changes in growth

pattern from concentric to eccentric, caused by tilting . . . changes in growth rate due to increased photosynthesis when adjacent trees [were] destroyed . . . age of trees within a given reforested avalanche track . . . ." Schaerer (1972) notes that factors other than avalanches can also affect tree growth, such as soil conditions, climate, exposure, and microtopography.

The presence of avalanche zones does not preclude the area from use. Protective measures can be employed to control or prevent avalanches. Such measures include devices which influence snow deposition, retaining structures to stabilize snow, diversion structures, avalanche arrestors to retard or arrest flow, and controlled release of avalanches (Mellor 1968). The Swiss, for centuries, have used such defensive devices to reduce the inherent avalanche hazards of an area.

Mass Movement. The general category of mass movement includes various types of phenomena. Mass movement generally refers to the downslope movement of material. This includes processes such as soil creep, rock glaciers, landslides, rockfalls, slumps, mudflows, and debris flows; although the exact terminology varies with different authors. Mass movement has been classified on the basis of types of movement and types of material, and on water content of material and stress level in the slope (Varnes 1958, Chandler 1977). Rate of movement and displacement are also used as a basis for classification (Bolt and others 1975). Landslides and Engineering Practice (Eckel 1958) is the most commonly referenced work on mass movement.

Mass movements and landslides, in particular, are caused either by a reduction of the shear strength of a material or an increase in the shear stress acting on the material (Cooke and Doornkamp 1974). Factors which cause an increase in shear stress include seismic effects; fault zones; climatic factors (i.e., heavy rains); vegetation changes; erosion; excavation; and changes in slope loading (Zaruba and Mencl 1969; Cooke and Doornkamp 1974; Bolt and others 1975; Sorensen, Ericksen, and Mileti 1975; Chandler 1977). Factors which decrease the shear strength of a material include weathering, progressive failure, changes in pore water pressure, long-term swelling, groundwater effects, and seismic effects (Zaruba and Mencl 1969, Bolt and others 1975, Chandler 1977). An individual case of mass movement could have one or several causes. A commonly used method of landslide investigation is to determine what factors caused the slope failure and relate this to other slopes in the area. The problem with this method is the conditions which promoted slope failure may have been caused by a single dominant factor. Yet this factor may not adversely affect other nearby slopes (Sangrey and Paul 1971).

A second type of approach to mass movement investigations (as opposed to finding specific causes) is to relate landslide occurrence to geology, vegetation, or topographic parameters. Slope inclination, in particular, has been related to the occurrence and rates of various types of mass movement (Beaty 1956; Owens 1969; Benedict 1970; Higashi and Corte 1971; Washburn 1973; Nilsen, Taylor, and Brabb 1976). Slope inclination is important in that it determines the relative effect of

gravity on the slope material. There is not one slope angle which in all cases can be related to mass movement. Local conditions are of overriding importance, and each specific study area (or portion of a study area) has its own threshold slope value above which mass movement is more likely to occur. Different types of mass movement may have different slope thresholds.

Rock type and aspect have also been related to mass movement occurrences. Aspect is an important factor in the location of landslides, probably due to its effect on soil moisture relationships. Beaty (1956) found that in southern California 70% of the landslides he studied occurred on north-, northeast-, or east-facing slopes. Certain rock types have been shown to be more susceptible to instability. This is especially true of rocks which contain or weather to produce montmorillonite.

The relationship between vegetation and slope stability is unclear. In some cases vegetation tends to promote slope stability, while in other cases vegetation tends to decrease slope stability. "A crucial factor in the stability of active slopes is the role of plant roots in maintaining the shear strength of soil mantles" (Swanston and Swanson 1976, p. 201). Vegetation, mainly trees, tend to stabilize slopes by several mechanisms, such as soil reinforcement by roots, reduction of pore water pressure, and increase in shear strength due to the surcharge produced by the vegetation's weight (Gray 1969, 1977; Kaliser 1972). Gray (1977) also notes that the increase in the shear strength of soil is directly related to the bulk weight of roots per

unit volume of soil. On the other hand, studies show that vegetation cover offers no protection against debris flows (Rapp 1960, Williams and Guy 1971). Three reasons are cited why forests would tend to contribute to the occurrence of debris flows. These are increased weight on slope, increased infiltration capacity, and reduced surface runoff.

After an analysis of the types of mass movement active in an area is completed, predictions of the relative slope stability of the area can be made. The prediction of slope stability is based on an understanding of both the existing modes of slope failure and its relationship to the geologic environment. Information on which such an analysis is based includes lithology, structure, slope inclination, aspect, surficial deposits, vegetation, seismic activity, surface and subsurface drainage, proximity to areas undergoing active downcutting, relief, relationship to existing areas of mass movement, and landforms (Blanc and Cleveland 1968, Bailey 1973, Cooke and Doornkamp 1974, Reeves 1975). Although these factors all relate to slope stability, the utilization of all of them would be difficult without detailed studies. Such studies, which would require much time and money, are not always feasible and an alternative approach must be used.

One practical approach to assessing slope stability is the use of a matrix. This approach involves picking two or more variables on which mass movement is dependent in the area. These variables are then related to each other in a matrix to predict relative slope stability. The relative slope stability map of Anchorage, Alaska made by Dobrovolny and Schmoll (1974) is a good example of this method. Dobrovolny and

Schmoll (1974) used slope and geologic materials as the two variables. On the side of the matrix was slope inclination, in groups of increasing slope steepness. The different geologic units (surficial and bedrock) were separated on the basis of their relative stability and composed the other side of the matrix. The geologic units were listed in the order of decreasing stability. Thus, as you move down the matrix rows, the slope angle and instability increase; across the columns of the matrix, the instability of the units increases. A number was then assigned to each surficial unit for each slope category indicating the relative stability of that combination. A map was then made showing the aerial distribution of the relative slope stability units.

Computer cartography is very applicable to a matrix approach to slope stability. As noted previously, with the use of computers the whole study area can be visualized as a series of much smaller areas. Information (slope, surficial geology, bedrock geology) can be stored for each of these subareas. A computer program can then be written which assigns a relative slope stability rating for each subarea based on the variables determined relevant. A map is then produced displaying the relative slope stability of the area. This map can then be compared to a map showing the locations of existing slope failures to check the relevance of the variables used. (Although this cross-checking could tend to be based on circular reasoning.)

Other approaches to slope stability prediction can also be utilized. Some of these approaches involve mathematical models, such as the finite and infinite slope analysis techniques. These techniques are

based on both field observations and laboratory measurements of physical properties. Chandler (1977) finds in some cases that these techniques tend to overestimate the stability of slopes. He believes the error is due to several factors: (1) samples too small, (2) inability to reproduce actual rates of deformation in the laboratory, (3) strength in isotropy in materials, (4) sample disturbance, (5) occurrence of progressive failure in the field, and (6) the effect of earthquakes.

Seismic Activity. An evaluation of an area's seismic activity is relevant to the structural and slope stability in that area. An earthquake has two effects on an area, ground shaking and faulting (Algermissen and Perkins 1973). Ground shaking affects the shear stress and strength of earth materials. Ground shaking can cause temporary foundation instability (i.e., liquefaction) and slope instability (landslides). Faulting can cause structural damage, changds in ground surface morphology, and changes in the mode of operation of the fluvial systems.

In defining seismic risk, various criteria can be used: (1) historic occurrence of earthquakes, (2) the area's tectonic setting, (3) site specification information such as wave attenuation and site amplification (Algermissen and Perkins 1973, Perkins 1974). From this type of information, seismic risk maps can be produced showing the ". . . geographic variation of a parameter that is appropriate for a particular application" (Perkins 1974, p. 13). The parameters that are displayed in seismic risk maps include zones of maximum earthquake intensity, zones of horizontal accelerations due to earthquakes, and frequencies of

earthquakes of certain intensities. Along with information as to the maximum earthquake intensities, it is also important to show the frequency of the more frequent, smaller sized earthquakes (Riznichenko 1970).

Volcanic Hazard. In volcanic terrain there are additional geologic hazards due to volcanic activity. Mount Baker in the Cascade Range of Washington provides a good example of volcanic hazards. "Increased thermal activity on Mount Baker raises many questions concerning possible hazards, especially if activity intensifies to include eruption of ash and lava" (Easterbrook 1975, p. 681). Hazards associated with mountain volcanoes include mudflows, debris flows, floods, rockfalls, snow avalanches, lava flows, pyroclastic flows, and the fall of airborne rock debris (Crandell and Mullineaux 1967, Easterbrook 1975, Keller 1976). The evaluation of volcanic hazards is a difficult problem, especially the prediction of future eruptions.

"A volcanic-hazards appraisal includes a forecast of the kinds of eruptions which are expectable, anticipation of volcanic events and the resulting deposits which will endanger human lives and property, and location of areas which can be affected by the events" (Crandell and Mullineaux 1975, p. 25). Crandell and Mullineaux use a six-step approach to volcanic hazard appraisal: (1) study the volcanic stratigraphy and surficial deposits, (2) from (1), try to infer genetic relationships, (3) develop a chronology of both the deposits and their related volcanic events, (4) map both the areas effected by volcanism and the frequency of events, (5) based on (4) and relevant new information, define volcanic

hazard risk zones, and (6) produce a map showing relative degree of risk due to different types of volcanic hazards. The more active the area, the more detailed information should be obtained to evaluate the volcanic hazards present.

Flooding. Flooding can also present itself as a geologic hazard in an area. An evaluation of the hazard produced by flooding would be important to the location and design criteria of structures and access facilities located at or near canyon bottoms. Of all the geologic hazards mentioned so far, floods seem to have had the most study. Techniques to determine both flood peak volumes and recurrence intervals are numerous in the literature. Most techniques are based on records of stream flow and are more accurate the longer the time that is covered in the data base. In many cases, stream flow data is absent or present for only a short period. In these cases, estimations can be made of flood volumes and recurrence intervals by using various geomorphic properties of the drainage basins (Thomas and Benson 1970).

Determination of Geologic Impact

Once the extant geologic environment of an area has been documented, changes in the environment due to a development can be ascertained. The basis of geologic impact is the changes to the geologic environment which occur in an area should the development be implemented. Change is the key word; how will the development change the rates and types of geologic process? The documentation of the geologic environment (discussed in the previous section) allows the geologist to have

an understanding of what processes are active, their current rates, and the sensitivity of these processes to change. From this information, predictions of geologic impact can be determined. It is important to note that methods and techniques to be used to determine and scale environmental impact have been almost completely ignored by government agency guidelines (Dickert 1974).

The use of a matrix to determine environmental impacts is one approach to the problem (Leopold and others 1971, Fischer and Davies 1973). Basically the matrix approach includes three steps: (1) identification of the effects on the environment caused by the proposed development; (2) estimation of the magnitude (degree, extensiveness, or scale) of each impact; and (3) determination of the importance or significance of each impact (Leopold and others 1971). The information obtained from each step can be combined into a "decison matrix" which shows the various impacts for each project alternative. Two sets of variables are used in the matrix, the environmental setting and the proposed alteration to the environment. The magnitude and importance are then determined and listed on the matrix for each interaction. Leopold (1974) cites several advantages of using the matrix approach.

1) The reviewer can easily determine how the writer ranked the relative importance of the various impacts.
2) Separating the magnitude and importance of an impact makes the writer separate value judgment from fact.
3) The matrix could show possible interactions that would otherwise be overlooked.

4) The matrix is expandable and detail can be added as needed.

5) Filling out the matrix gives a logical outline for the report.

A matrix approach would probably be most useful in weighing the environmental effects of various alternatives to a proposed development.

Ski area developments have characteristic ways in which they alter the environment. Vegetation reduction and reshaping of the land surface are the two most important. These alterations produce specific impacts, such as increased soil erosion, increased slope instability, increased sediment yield and load, and possible changes in the mode of operation of fluvial systems. These impacts would be likely to occur in all ski areas. A specific ski area can also have other impacts that are due to the local geologic environment.

Soil Erosion

Soil erosion should be evaluated in an environmental geologic analysis of a proposed ski area. A comparison of the amounts and rates of soil erosion before, during, and after construction should be made. Soil erosion tends to increase due to vegetation reduction, compaction of the ground surface, interruption of surface drainage, and alteration of the soil surface, all of which occur in the construction of a ski area. One objective way to describe soil erosion is by using a soil loss equation.

Several authors have produced soil loss or erosion equations. Variables incorporated into these equations include inherent soil erodibility, overland flow characteristics, rainfall amounts and intensity,

surface roughness, slope steepness, and slope length (Horton 1945, Musgrave 1947, Anderson 1969, Kirkby 1969, Cooke and Doornkamp 1974). The equations used by Anderson (1969) are particularly useful in that they predict both soil erodibility and the amount of soil loss (for an example of an erosion sensitivity of soil map, see Figure 4). The amount of soil loss is dependent on the soil erodibility and vegetative cover. With these equations, changes in vegetative cover, due to the development, can be modeled and related to changes in soil loss over the area. These future soil loss amounts can be compared to the current soil loss amounts predicted by the equations. Rather than emphasizing actual amounts of soil loss, the percent change in soil loss from current to development status should be shown. In using percent change, the inherent errors of the soil loss equations are minimized.

Slope Stability

The slope stability of an area will also be affected by a ski area development. Again vegetation removal plays a large role. An increase in slope instability, both in terms of creep and more catastrophic failures, is directly related to the removal of forest vegetation (Gray 1969, 1970, 1977; Swanson and Dyrness 1975; Swanston and Swanson 1976). Usually the main effect of tree removal on slope stability is not apparent until some time after the cutting. This is because the ". . . effectiveness of rooting is a factor in soil shear strength decreases with age" (Gray 1977, p. 17). Gray (1977) thinks soils reach their minimum effective strength due to root support within 5 to 15 years after cutting. Most of the studies on tree removal and slope stability were

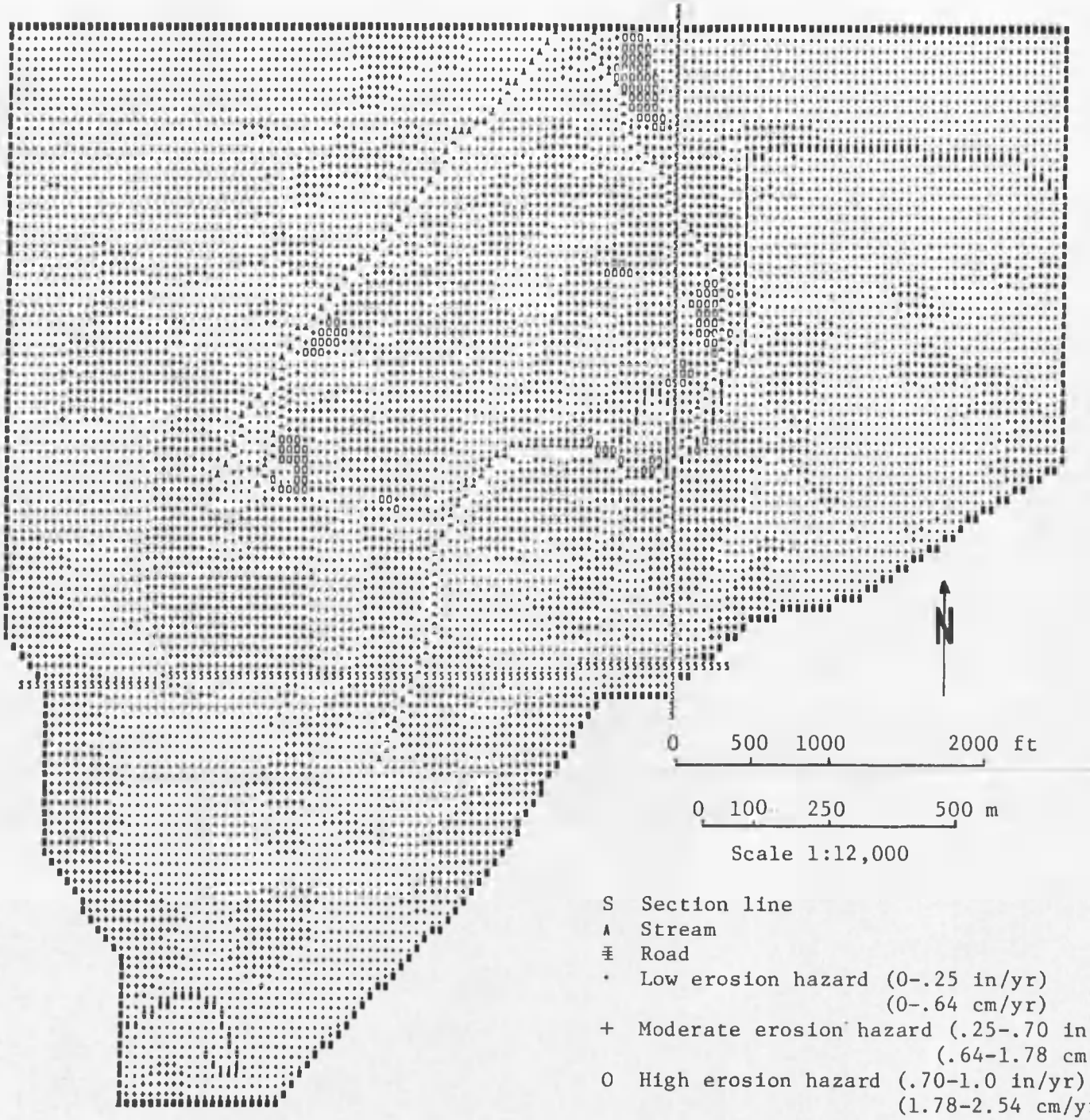

Figure 4. Erosion Sensitivity of Soils. -- Erosion hazard is the inherent erodibility of the soil. It does not take vegetative cover into account.

done in areas where whole mountain sides were cleared of vegetation. The effect caused by the clearing of ski trails and lift lines will probably not be quite as profound because only narrow paths are cleared of vegetation. The effect on slope stability will be the greatest at the cleared area and will decrease away from it. Therefore, the placement of ski slopes can be useful in determining the post-development slope stability in the area.

Fluvial System

Increased mass movement, increased soil erosion, reduced vegetation, and altered runoff characteristics in an area will affect that area's fluvial systems. Vegetation reduction can cause increases in the snowmelt rate; changes in the snow pack (increased winter snow pack, decreased spring snow pack); increases in total amount of streamflow; and changes in the flood peaks (increased early in the snowmelt season, decreased late in the snowmelt season) (Anderson 1956; Reinhart, Eschner, and Trimble 1963; Goodell 1972; Lull and Reinhart 1975). These effects, coupled with increases in sediment load and yield, have the capability to greatly change the operation of the fluvial systems. Schumm (1977) indicates that increased water discharge and sediment load could cause adjustments to the stream channels such as increased width, increased meander wavelength, decreased sinuosity, increased width/depth ratio, changes in slope, and changes in depth. Thus a ski area development can have a profound effect on stream channel morphology. Even if the changes to the stream channel are small, they may cause a change in the mode of operation of the entire fluvial system. This is especially true if the

stream is operating near a threshold. (For a complete discussion of stream threshold, see Bull, in press). A change in the mode of operation of a stream would mean that a stream in a depositional mode would change to an erosional mode or vice versa.

It should be noted that the effect of changes of variables on a fluvial system is not completely understood. The large number of variables and their complex interaction cause this uncertainty. "A drainage system is complex and, therefore, when a change occurs the response of the system will also be complex" (Schumm 1977, p. 152). The operation of geomorphic thresholds also adds to the difficulty of understanding future stream system changes. "Geomorphic thresholds exist and result in abrupt and unexpected landform changes" (Schumm 1977, p. 122). This should not discourage the worker in the prediction of fluvial system changes, but rather caution him that accurate quantitative predictions may be difficult or impossible to make.

Identification of Geologic Constraints

Geologic constraints are limitations imposed on a project by the extant geology. The concept of geologic constraints is an extension of the concept of geologically induced costs (discussed in Chapter II). A geologically induced cost becomes a geologic constraint when the cost of correcting the situation is no longer economically feasible. For example, a portion of a project area has expansive soils; not all of the area has these soils present. It is determined that the cost to control the expansive soils is not economically feasible. In this case, the

expansive soil would represent a geologic constraint. Areas which had the expansive soil present could not be used for structure locations.

The identification of geologic constraints is most effectively accomplished when there is close communication between the project developer and geologist. The geologist must relate to the developer specific information: (1) the existing geology of the area, (2) special geologic conditions which would increase costs, (3) the geologic impact of the development, (4) mitigation guidelines to reduce the geologic impact, and (5) the costs to implement these mitigation guidelines. The developer would also provide input on the above costs. From this information, the developer and the geologist can determine what geologic conditions and impacts represent geologic constraints. The geologist can then identify the geologic constraints and relate to the developer their location and extent in the proposed development area. Thus the nature of the geologic constraints is dependent on several factors. These are the extant geology of the area, the impacts produced by the development, the size of the project, and the financial limitations on the proposed project. This discussion makes it clear that geologic constraints are determined by the nature, size, and location of the proposed development. What would represent a geologic constraint in one project may not be considered a constraint in another project. Thus, the nature of geologic constraints is project-dependent and must be individually evaluated for each specific project.

CHAPTER V

CASE STUDY: EXPANSION OF THE WILLIAMS SKI AREA

Chapter V provides the reader with an example of environmental geologic analysis of a proposed ski area. This case study will serve as an illustration of the methods and procedures described in Chapter IV. This geologic study of the Williams Ski Area is a small portion of a much more detailed economic feasibility study. The whole feasibility study is being undertaken by the City of Williams, Arizona. The study will be submitted to the Kaibab National Forest, on whose land the development is planned. The geologic analysis presented in this chapter is in the format of an environmental impact statement.

Project Description

Location

Williams Ski Area is situated on Bill Williams Mountain, Coconino County, Arizona (Figure 5). The mountain is located between 35°10' and 35°14'25"N latitude and 112°10' and 112°14'45"W longitude. The mountain is near the southern margin of the Colorado Plateau physiographic province. The proposed expansion area (study area) is a roughly rectangular area on the north side of the mountain (Figure 6, in pocket). The peak of Bill Williams Mountain is located at the very southern end of the study area.

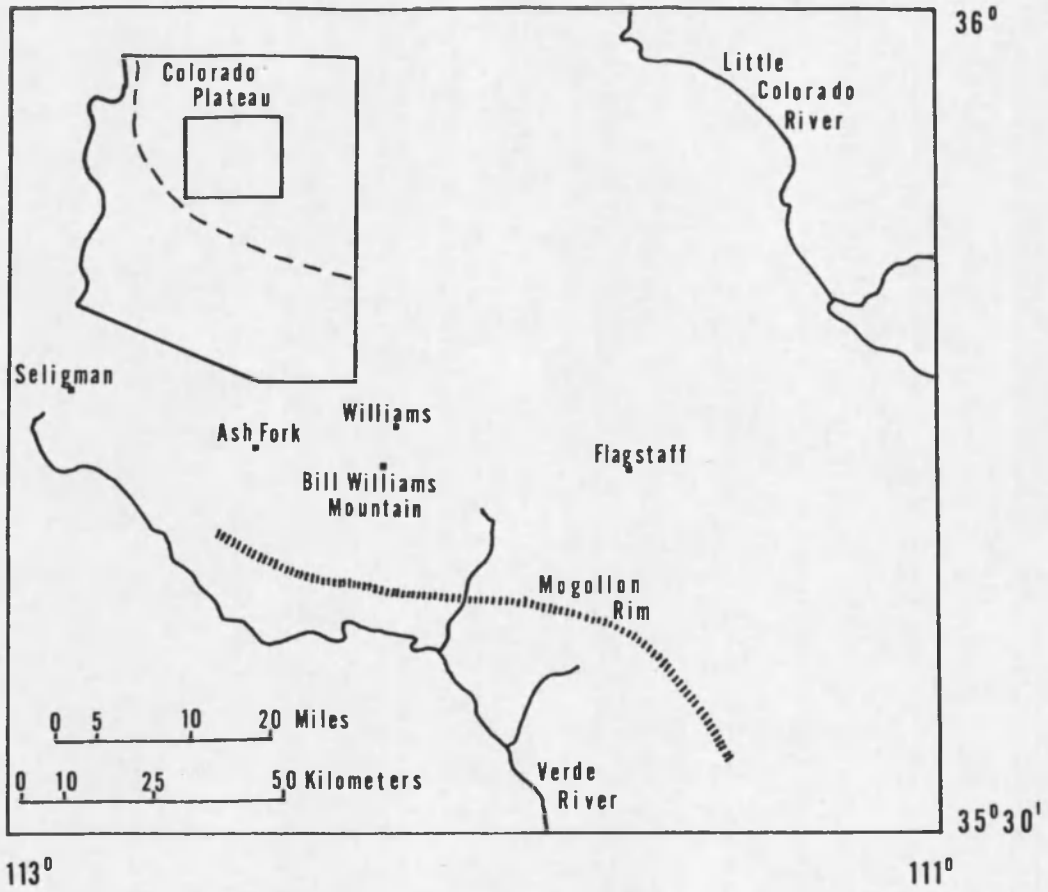

Figure 5. Regional Physiographic Map of Northern Arizona.

Existing Facilities

A small ski area (Williams Ski Area) currently exists on the north side of Bill Williams Mountain (Figures 7 and 8). The area has two surface lifts, a poma lift with 366 m (1200 ft) surface length and 116 m (380 ft) vertical rise, and a rope tow with 198 m (650 ft) surface length and a 34 m (110 ft) vertical rise. The rope tow services a small beginner slope, while the poma lift provides access to two mainslopes and a narrow ski trail. Support facilities consist of a lodge, equipment shed, parking lot, and access road. Electric power is generated on site; bottled gas and water are trucked into the area. Sewage is stored in cement receptacles and trucked out of the area.

Proposed Facilities

The proposed expansion of the Williams Ski Area will be to the west of the existing area (Figures 7 and 9). If the development is completed, the result will be a medium-sized ski resort. The basic facilities produced as a result of the expansion include:

1) One 2011 m (6600 ft) (slope length) double chair lift with a vertical rise of 548 m (1800 ft) and a loading/unloading terminal midway up the lift line.
2) One 305 m (1000 ft) surface lift with a vertical rise of 55 m (180 ft).
3) Four main ski trails (one of which is along the main lift line) and one beginners slope.

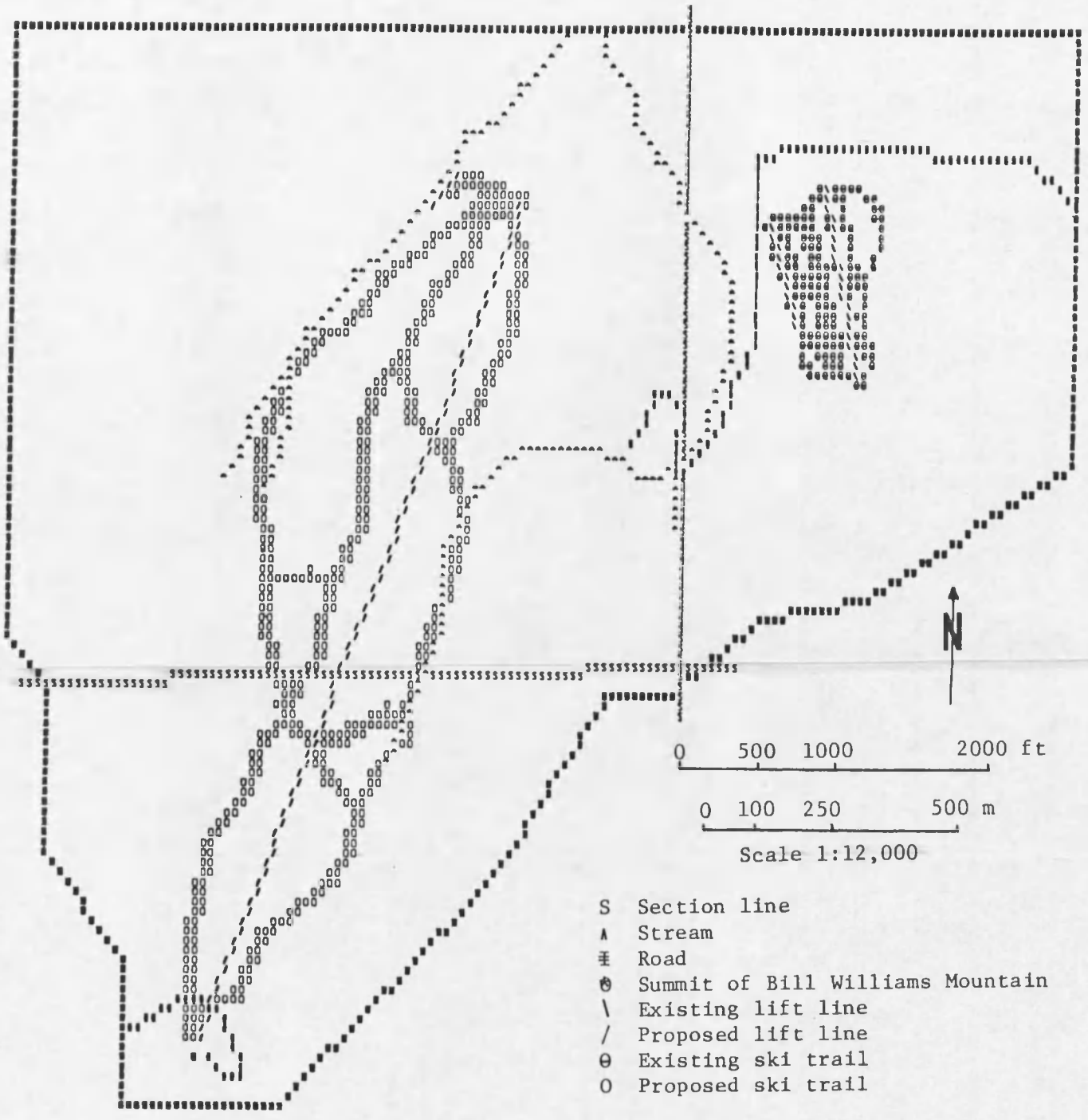

Figure 7. Proposed and Existing Facilities.

Figure 8. Williams Ski Area. -- July, 1978. Poma lift line is narrow clearing in center of picture. Rope tow lift line runs along the left edge of small clearing on left side of picture. Lodge and equipment shed are hidden from view near bottom left edge of the main ski slope.

Figure 9. Bill Williams Mountain. -- Main lift line will come down ridge to left center of picture.

4) A 1023 sq m (11,000 sq ft) base lodge (located adjacent to the bottom chairlift terminal and the bottom terminal of the surface lift.

5) A 450 car, 10 bus parking lot and 0.48 km (0.3 mile) access road (located northeast of the lodge).

6) A 144 sq m (1550 sq ft) maintenance building.

7) Electrical and/or gas system.

8) Water system.

9) A self-contained sewage system.

Figure 9 shows the proposed locations of the lift lines and ski trails. The exact location of the buildings, parking lot, and access road have not been determined by the developer and are not shown on Figure 9.

Geologic Setting

Regional Setting

Bill Williams Mountain is located near the southern margin of the Colorado Plateau physiographic province. The Colorado Plateau extends into portions of Utah, Colorado, Arizona, and New Mexico. The Basin and Range Province lies to the west, south, and southwest of the Colorado Plateau. The two provinces are separated by the Mogollon Rim in Arizona.

The Colorado Plateau is composed of dominantly flat-lying Paleozoic and Mesozoic sedimentary rocks, a much smaller amount of Precambrian rocks, and a partial surface covering of Cenozoic volcanics. The pre-Cenozoic rocks are cut by northeast- and northwest-trending high-angle

faults. In many instances, the surface expression of these faults is generally east-facing monoclinal folds (Hunt 1956).

Local Setting

Bill Williams Mountain is the southernmost of a group of five silicic volcanic centers in the San Francisco volcanic field. The volcanic rocks on the mountain range in composition from basalts to dacites. Bill Williams Mountain basically consists of a central complex of radially oriented spines within and partly underlying a cluster of domes and flows. Radiometric dates on the volcanic rocks on Bill Williams Mountain range in age from almost 6 to 3.5 m.y. (Pugmire 1977).

Geologic History of Bill Williams Mountain

Pugmire (1977) outlines a basic sequence of events which occurred in the formation of Bill Williams Mountain. The inferred sequence of events includes dacite eruptions forming an asymmetric composite volcano, blocking of the main vent by solidification of the dacite, volcanic quiescence and erosion, renewed volcanic activity resulting in fracturing of the existing volcano and the injection of dikes west of the current summit, eruptions of dacite from secondary vents resulting in capping of the eastern portion of the volcano and a rafting away of the southern portion, erosion, and emplacement of the domes and dikes.

Bill Williams Mountain has undergone further erosion since the end of volcanic activity. There have also been periods of reduced erosion and land surface stability as evidenced by the developed soil profiles present on the mountain. During the Quaternary, the mountain

experienced an environment colder than present. Patterned ground, rock glaciers, and frost rubble present on the mountain indicate a Pleistocene climate with extensive frost action. There is no clear-cut evidence for the presence of glaciers on Bill Williams Mountain, although small perennial snow fields probably existed.

Documentation of the Geologic Environment

Topography

Bill Williams Mountain rises to an elevation of 2820 m (9256 ft) and has a maximum relief of 670 m (2200 ft). The study area ranges in elevation from 2820 m (9256 ft) to 2245 m (7370 ft). The mean elevation of the study area is 2450 m (8043 ft). Figure 6 is a topographic map of the study area. This map was created by enlarging the 7½' topographic sheet Williams 4 NW, Arizona.

Figure 10 is a computer-produced topographic map of the study area which was produced by gridding a map like Figure 6. Grid lines were spaced 0.635 cm (.25 in) apart, 38 m (125 ft) at the map scale. Elevations were recorded for each grid intersection to the nearest 1.52 m (5 ft). These elevations were used as input to produce Figure 10. The same elevations were also used as input to TOPO III, a computer terrain analysis program. TOPO III output was used to produce slope maps. Thus comparing Figures 6 and 10 provides a check on the density and accuracy of the TOPO III input. The close match of the 61 m (200 ft) contour lines on both maps indicates that the computer elevation data accurately portrays the actual topography of the mountain.

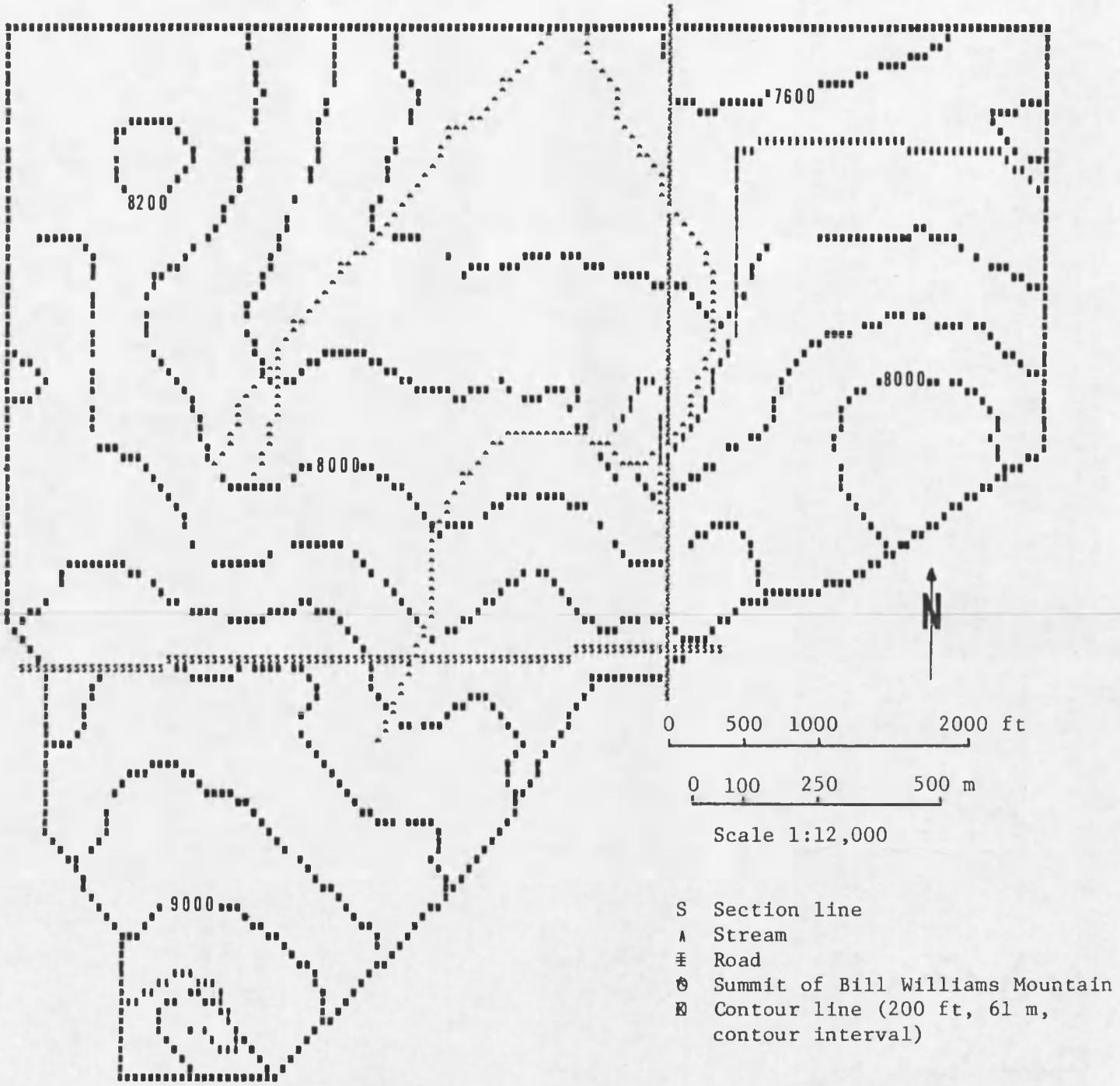

Figure 10. Computer-produced Topographic Map.

Bedrock Geology

The geology of an area can be viewed from several different perspectives. The area can be studied and mapped in terms of the bedrock geology or the surficial geology. Bedrock refers to solid rock which may or may not be exposed at the earth's surface. Bedrock geologic maps classify the bedrock in terms of rock type (i.e., sandstone, shale, dacite, granite). Surficial geology refers to the unconsolidated material existing on the earth's surface (i.e., talus or alluvium). Therefore, a bedrock geologic map can be constructed for an area even though the bedrock is not exposed at the earth's surface, but rather is covered by surficial material. Surficial geology refers to the materials which exist at the earth's surface. Consequently, if bedrock is exposed at the surface, it is classified as bedrock on a surficial geologic map. The bedrock geology and surficial geology on Bill Williams Mountain are closely related. Specific bedrock units are identical in their location and distribution to specific surficial geologic units. In discussing the bedrock geology, the reader should refer to the surficial geologic map (Figure 3). Letters and numbers in parentheses following bedrock names indicate the corresponding surficial geologic units on Figure 3.

Dacite is the primary rock type exposed in the study area. The dacites are of Tertiary age. Four rock types are exposed in the area: (1) earth dacite flows (D_1 and the B associated with it), (2) late dacite flows (D_2 and the B associated with it), (3) dacite dikes (linear orientated B), and (4) dacite domes (D_3 and the B surrounds). The bedrock terminology is after Pugmire (1977), and the units are listed in

order from oldest to youngest. The early dacite flows are usually non-vesicular, flow-banded, and slope formers. The late dacite flows are not as flow-banded as the early flows. Both flows are tan to grey and oxidized to salmon pink. They are both massive and porphyritic with an aphanitic groundmass. The phenocrysts consist of plagioclase, hornblende, biotite, and quartz which vary in size from 1 to 25 mm. "In hand specimen, these two units are practically identical and therefore classification of the rocks into one of the two respective units |early dacite flows and late dacite flows| were based on the vent area from which the magma erupted" (Pugmire 1977, p. 43). Both flows have secondary magnetite and secondary clay alteration of the plagioclase (Pugmire 1977). There is one striking difference between these two flows; the early dacite has undergone intense weathering and forms a grus. The grus varies in thickness from several centimeters to three meters. The bedrock outcrops of the early dacite are friable, although a surficial case hardening (probably due to iron and silica enrichment) is present.

The composition of the dacite domes and dikes is similar. Pugmire (1977) suggests that the dikes acted as feeders for the domes. In outcrop the dacite domes are massive to blocky with extensive breccia aprons surrounding them (on Figure 3, the domes are the extensive outcrops of B, the breccia aprons are D_3). In hand specimen, the dacite domes and dikes are tan to grey and oxidized to salmon pink. They are flow-banded and porphyritic with an aphanitic groundmass. Phenocrysts consist of plagioclase, hornblende, biotite, and quartz and range in size from 1 to 5 mm. The two northern domes in the study area do not

contain quartz and contain only small amounts of biotite. In outcrop the dikes are vertical, non-vesicular, and jointed perpendicular to the dike trend.

The variation between the different rock types in the study area is small. All the rocks are porphyritic with an aphanitic groundmass. The phenocryst assemblage is also similar for all rock units. The main difference between the different rock types is their state of weathering. All the rocks have a thin weathering rind, but only the early dacite flows produce grus. Thus all the rock types except the early flows have similar engineering characteristics. These early flows have shear strengths which are much less than the other rock types due to the extensive weathering they have experienced.

Surficial Geology

The surficial geologic units are shown on Figure 3. There are three basic types of surficial units--bedrock-controlled slopes (B on Figure 3), forested debris slopes (D on Figure 3), and talus slopes (T on Figure 3). These units are further subdivided on the basis of engineering characteristics and suitability for proposed uses. The surficial geology was mapped in the field on air photos. This information was then transferred to a map like Figure 6. Then the map was gridded and the surficial geologic units were input into the SYMAP mapping program to produce Figure 3.

Bedrock-controlled Slopes. Areas classified as bedrock-controlled slopes (B) are composed of actual bedrock outcrops and areas of predominantly bedrock outcrops with some thin regolith covering. The rationale for including areas with a thin regolith in this category is that these areas have engineering characteristics similar to actual bedrock outcrops. Consequently, boulders protruding from bedrock-controlled slopes are actually bedrock and cannot be removed by pushing them with heavy equipment. These bedrock areas would be the most difficult to reshape of all areas in the proposed development.

Forested Debris Slopes. Debris slopes account for more than one-half of the total project area. The debris slopes are divided into three subunits: (1) D_1 debris slopes forming on the early dacite flows, (2) D_2 debris slopes forming on the late dacite flows, and (3) D_3 debris slopes composed of large boulders and usually forming the rubble apron around the dacite domes and dikes. Table 3 gives a rough estimate of the surficial composition of the different debris slopes. Particle size was also used as a criterion for separating the different debris slopes. Samples were taken to determine the particle size distributions of the surficial material: (1) D_1 mean particle size 4 mm, size ranged from less than 2 mm to 512 mm; (2) D_2 mean particle size 16 mm, size ranged from less than 2 mm to 512 mm; (3) D_3 mean particle size 64 mm, size ranged from less than 2 mm to 1064 mm. It should be noted that D_1 and D_2 debris slopes have a relatively smooth surface, while D_3 debris slopes have a higher surface roughness and are therefore less suitable for ski trail location.

Table 3. Surficial Composition of Forested Debris Slopes.

Forested Debris Slope Unit	Soil <4 mm	Rocks 4-305 mm	Boulders >305 mm	Good Vegetative Cover[1]	Other Vegetative Cover[1]	Bedrock
D_1	10%	15%	5%	44%	20%	6%
D_2	11%	23%	2%	49%	15%	0%
D_3	6%	20%	13%	36%	6%	19%

Talus Slopes. Talus slopes are composed of large boulders with very little finer material present. These slopes are not talus slopes in the usual sense of the word, because they do not always form at the base of a cliff. The only vegetation on these slopes is aspen trees. Slopes identified on Figure 3 as T/D_3 are transitional between talus and D_3 debris slopes. Talus slopes have a mean particle size of 384 mm and a particle size range from 64 to 2048 mm.

Table 4 shows the suitability of the different surficial geologic units for specific uses. The suitability classes used in Table 4 were arbitrarily assigned. Different criteria (to determine suitability) were used depending on the intended use. Buildings, roads, and parking lots have similar needs and limitations in terms of the engineering characteristics of the material on which they are constructed. The important criteria for buildings, roads, and parking lots include a stable surface which is not prone to landslides or other slope failures and the earth's materials should be easy to excavate and move to allow foundation placement and reshaping of the land surface. Ski lifts have different criteria which affect the suitability of earth materials for this use. The material should be strong enough to allow solid placement of the lift towers (thus bedrock provides the most suitable locations for lift tower placement), and the material should be stable (not prone to landslides or other slope failures). The criteria used to determine the suitability of surficial units for ski trail placement include surface roughness (large boulders and bedrock sticking above the ground would have to be removed to produce a smooth skiing surface), and the

Table 4. Suitability of Surficial Geologic Units for Different Uses.

Surficial Geologic Unit	Buildings	Roads, Parking Lots	Lifts	Ski Trails
B	2[a]	3	1	4
B (inside D_1)	3	2	2	3
D_1	1	1	3	2
D_2	1	1	3	1
D_3	4	4	4	2
T	5	5	5	5
T/D_3	5	5	5	5

[a] 1 = most suitable, 5 = least suitable

ease with which the ground can be reshaped (i.e., exposed bedrock knobs must be removed with dynamite, which is expensive and time-consuming).

Slope

The actual slope values on Bill Williams Mountain were computed by using TOPO III computer terrain analysis program (Grender 1976). As previously noted, the input to the program was an array of elevation data. TOPO III computes the slope of a point by comparing elevation values on opposite sides of the point. The distance between the compared elevations is 38 m (125 ft). Thus the computed slopes represent the "average" slope on the ground across a 76 m (250 ft) area. For each point TOPO III makes several pairwise comparisons; the value used to produce maps is the greatest of all the comparisons around each point. The slopes are calculated as tangents; thus the maps are isoclinal slope maps. Two slope maps are presented, a map of skier slope classes (Figure 1), and a map of slopes using quantiles (Figure 2).

The skier class slope map (Figure 1) shows the location of slopes of different skier categories. Figure 1 shows that the proposed ski area will consist of mainly intermediate and advanced ski terrain. The map shows that intermediate terrain on the mountain is separated by short sections of advanced terrain. Field work has shown this is not the actual case. Near the start of both the west and central stream sections are passages of intermediate terrain. Thus it is possible to ski intermediate terrain from the top to the bottom of the mountain.

Soils

The soils present in the study area are closely related to the surficial geology. Two basic soil types (based on the U. S. Department of Agriculture agricultural classification of soils) are present in the study area. These are Lithic Udorthents on D_1 slopes and Typic Cryothents on D_2 slopes (Figure 10). Talus and D_3 slopes do not have soils present, only a thin layer of organic and mineral material between the boulders. On the basis of the Unified Soil Classification System (which is an engineering classification for soils), these soils are identical and are classed as SP-SM. SP-SM indicates poorly sorted soils with fines that have little or no plasticity (the fines are silts rather than clays). Tables 5 and 6 list the physical characteristics of each of the soils.

Based on a chart published by Gillott (1968), specific engineering characteristics can be associated with SP-SM soils. The engineering characteristics of these soils are: (1) potential frost action, slight to high; (2) compressibility and expansion, very slight; (3) drainage characteristics, fair to poor; (4) compaction equipment needed, rubber-tired roller, sheepsfoot roller (and there must be a close control of soil moisture during compaction); and (5) typical unit dry weight, 1.52 to 1.90 kg per cubic meter (120-135 lbs per cubic foot).

The Lithic Udorthents have the highest potential for erosion and the lowest potential for revegetation. These soils have the highest erosion potential and lowest revegetation potential due to several factors. They are the shallowest of the soils present, they show a rapid

Table 5. Description of Soil on D_1 Surficial Geologic Unit. -- Based on Unified Soil Classification System, an engineering classification.

Typical name	Fine-medium sand with cobbles; approximately 3-12% nonplastic fines.
Gradation	Poorly graded (uniformly graded, coefficient of uniformity = 8.6, coefficient of curvature = .74); particle size range from silt to coarse gravel.
Size distribution	Size distribution of the fraction finer than 76 mm: gravel = 8% sand = 86% fines = 6%
Plasticity of fines	None; fines have quick to medium dilatancy and slight to medium toughness near plastic limit.
Maximum particle size	160 mm
Mineralogy	Surficial rocks hard, yet subsurface rocks are typically friable and grusified. Weathering rinds present on both surface and subsurface rocks. The bedrock is a dacite which is massive and porphyritic with an aphanitic groundmass. Phenocrysts include plagioclase, hornblende, biotite, and quartz; size range from 1-10 mm.
Grain shape	Angular to subrounded
Color	10 YR 4/3
Moisture	Dry
Degree of compactness	Loose
Group Symbol	SP-SM
Limitations	High erosion potential; low revegetation potential.
Name	Lithic Udorthent

Table 6. Description of Soil on D_2 Surficial Geologic Unit. -- Based on Unified Soil Classification System, an engineering classification.

Typical Name	Fine sand with cobbles; approximately 6-12% nonplastic fines.
Gradation	Poorly graded (uniformly graded, coefficient of uniformity = 11.3, coefficient of curvature = .72); particle size range from silt to coarse gravel.
Size distribution	Size distribution of the fraction finer than 76 mm: gravel = 8% sand = 84% fines = 8%
Plasticity of fines	None; fines have quick dilatancy and slight to no toughness near plastic limit.
Maximum particle size	140 cm
Mineralogy	Surface and subsurface rocks hard with some weathering rind. The bedrock is dacite which is massive and porphyritic with an aphanitic groundmass. Phenocrysts include plagioclase, hornblende, biotite, and quartz; size range from 1-25 mm.
Grain shape	Subangular to subrounded.
Color	10 YR 3/2
Moisture	Dry
Degree of compactness	Dense
Group Symbol	SP-SM
Limitations	None
Name	Typic Cryorthent

reduction of permeability with depth, they have a very thin to nonexistent litter and humus cover, they consist of mostly sand-sized single mineral particles, and they have the lowest vegetation density of all the soils in the area. Because the soil is shallow and underlain by relatively impermeable bedrock, water tends to run off rather than infiltrating into the soil. The absence of an organic cover on the surface allows soil particles to be moved by running water. The lack of this cover also tends to reduce soil moisture, and thus the probability of seed getting established in the soil is low.

Geologic Hazards

Snow Avalanche. Snow avalanche hazard in the area is very low. No past or present avalanche scars are found on the mountain. Also none of the study area is above treeline, and thus there are no starting zones for snow avalanche.

Mass Movement. There is no evidence of rapid slope failure on Bill Williams Mountain. The only type of mass movement apparent is soil creep. The presence of creep was identified by bent tree trunks. This creep is apparent only on slopes with steep slope inclinations (greater than 40%) and generally north aspects. The locations of this apparent creep are small and isolated and tend to occur in aspen groves.

Seismic Activity. There are no active faults in the study area. Algermissen and Perkins (1973) have produced probable seismic activity maps for the combined areas of Utah and Arizona. The maps show that the

average horizontal accelerations (in percent of gravity) for the study area with a 50 year return period is less than 1%, and that the 90% probable extreme horizontal accelerations (in percent of gravity) for the study area with a 50 year return period is between 10 and 20%. These listed accelerations are for rock, and thus the accelerations in surficial material could be different. Sumner (1976) indicates that the study area is in the Transitional seismicity zone. The Transitional zone has had historic earthquakes of mostly less than 4.9 on the Richter scale, although this zone has also had some historic earthquakes of between 5.0 and 5.9 on the Richter scale (Sumner 1976, p. 2). The Transitional seismic zone is one of the more seismic areas in Arizona (Sumner 1976).

Volcanic Activity. There is no evidence of current volcanic activity on Bill Williams Mountain. As noted before, the youngest volcanic rocks on the mountain are over 3 m.y. old. Thus, the hazard of volcanic activity on Bill Williams Mountain is very low.

Flooding. There is no field evidence to indicate that flooding would represent a hazard to the proposed development. The study watershed is small and stream flow is produced only by snowmelt. The upper portions of the stream courses in the area are covered by organic debris. This indicates that there are insufficient amounts of water flowing to cause erosion or deposition. The lower portions of the streams do not have an organic covering, indicating that erosion/deposition is actively occurring. The lower portions of the stream channels are deeply

entrenched below the rest of the land. Thus if larger water volumes were produced in the watershed, they would probably be easily contained within the entrenched channel and flood waters would not endanger structures or facilities of the proposed development.

Geologic Impact of the Proposed Project

The primary geologic impact of the proposed expansion to the Williams Ski Area is increased erosion. Current and projected rates of erosion for the study area were modeled by using equations presented by Anderson (1969). Using the computer-produced slope and surficial geology map, soil erosion was calculated individually for each print location on the slope map. These parameters were calculated for each 15.24 m (50 ft) by 19.05 m (62.5 ft) area. Figure 4 shows the erosion sensitivity of the soils over the study area.

The erosion sensitivity of a soil is the inherent erosion hazard of the soil, without considering the vegetation present on the soil surface. The general factorial equation for the computation of erosion hazard (erosion sensitivity) is (Anderson 1969, p. 1):

erosion hazard = basic erosion rate X erodibility coefficient X precipitation coefficient X slope coefficient

The basic erosion rate (in inches per year) is a function of soil depth, texture, and permeability. The erodibility coefficient is a function of the detachability of the soil surface, the permeability of the soil horizons, changes in soil permeability with depth, and the percent of coarse rock fragments on the soil surface. The erosion hazard is the

inherent erodibility of the soil or the sensitivity of the soil to erosion. The erosion hazard is portrayed for the area on Figure 4. The actual soil loss due to erosion is calculated by multiplying the erosion hazard by a vegetation coefficient. The vegetation coefficient takes into account the vegetation density, vegetation type, and the amount of organic cover on the soil surface. The concepts of erosion hazard and actual soil loss must be kept separate. The erosion hazard of a soil remains constant before, during, and after development (it is an inherent property of the soil). The soil loss due to erosion is not constant before, during, and after the development because the development changes the vegetation cover in the area and thus the amount of soil loss.

The current calculated soil loss for the study area is 5.364 hectare-centimeter/year (.4331 acre-feet/year). The projected future soil loss was calculated for three vegetation conditions: (1) all vegetation is completely removed from the lift lines and ski trails, (2) a 2.54 cm (1 in) thick blanket of wood chips is applied to the lift lines and ski trails, and (3) the lift lines and ski trails are revegetated to the same vegetation density as on the current ski trails in the existing area. Complete removal of vegetation would (option 1) result in a 252% increase in soil loss from the current rate. Covering the disturbed area with a 2.54 cm (1 in) blanket of wood chips would result in a 4% decrease in soil loss from the current rate. If the vegetation density was the same as the current ski trails, there would be a 3.7% increase in soil loss from the current rate. The vegetation density of

the ski trails and slopes would be lowest after construction and would increase with time. Thus soil erosion will be at a maximum during and immediately after construction and will decrease with time after construction.

Mitigation Guidelines for Soil Erosion

The natural ground surface should be disturbed as little as possible, and the vegetation should be removed only when absolutely necessary. Mulching the cleared areas (mostly trees are cleared) with wood chips will reduce the immediate soil loss due to construction. The cleared areas should also be seeded to allow annual plants to further stabilize the soil. The area should be revegetated with both Forbes and grasses. The mature height of anything planted should not be taller than .5 m. Tall plants interfere with skiing when the snow depth is low. Forbes such as cushion Erigonum, sticky geranium, mountain lupine, and Rydberg Pentemon could be used. Grasses used for revegetation include Kentucky Bluegrass, Meadow Brome, Mountain Brome, smooth Brome, che Reedgrass, and intermediate Wheatgrass. (These plant species were taken from Plummer 1970). Using these guidelines, the amount of increased soil loss should be only 1-2% more than the current amount.

Geologic Constraints on the Proposed Project

There are no completely binding geologic constraints on the proposed development. Table 4 lists the suitability of the surficial geologic units for use in the development. Even the units listed as highly

unsuitable for a particular use can be used with additional engineering techniques; cost is the main drawback to their use.

Summary

The purpose of this section is three-fold: (1) to briefly review the conclusions of the environmental geologic analysis of the proposed Williams Ski Area, (2) to review the methods and techniques used in this study, and (3) to evaluate how this study might compare with the types of environmental geologic studies that should be done at other proposed ski areas.

Conclusions

The proposed expansion of the Williams Ski Area will not create any major geologic impact to the geologic environment. Soil erosion is the main geologic impact of the development. Proper construction techniques, mulching, and revegetation of disturbed areas should insure that the soil erosion during and after construction will be only 2% greater than the predevelopment soil erosion rate. Increased soil erosion will also increase the sediment load of the streams and possibly cause increased sedimentation in the downstream reservoirs.

Another geologic impact of the proposed development is changes in the mode of operation of the streams in the area. Changes in the fluvial system are mainly caused by reduction of hillslope vegetation and increased sediment load. Possible changes to the fluvial system include increases in the total amount of stream flow, increases in flood peaks in the early snow melt season, and decreases in flood peaks in the late

snow melt season. The effect these changes will have on the morphology of the stream channels is difficult to predict. Possible changes in the stream channel morphology include increased width, decreased sinuosity, changes in slope, and changes in depth (Schumm 1977). The impact of these changes will probably be small and will not greatly affect the fluvial system downstream.

Methodology

A wide variety of methods and techniques were used in this case study. Many of the techniques (field mapping, air photo interpretation, soil and rock sampling) are traditional to the science of geology. Non-traditional approaches, most noticeably the application of computers, were also utilized. This study also emphasized a systems-wide approach to evaluate the interaction between the extant geology and the proposed development.

The application of computers greatly aided this study. Computers were used to produce maps, analyze terrain data, and predict changes in soil erosion due to the development. Because computer techniques are based mainly on office work, field checks were done to assure the accuracy of the computer-generated data. Many different maps were produced in the course of this study. For example, four different skier class slope maps (Figure 1) were produced. Each map used a different search radius in calculating the slopes. These four maps were evaluated in the field, and the one which most accurately portrayed slopes in the area was included in this thesis. The erosion sensitivity of soils map (Figure 4) was also field checked. Prior to completing this map the author

had determined, from field observations, which areas are the most subject to soil erosion. The computer-generated map validated these initial assumptions.

Although computers represent a valuable tool which can be used in geology, they are not perfect. Great care must be taken in the program development and data input stages. The computer is no more intelligent than the person who writes the programs. To prevent the "garbage in, garbage out" syndrome, care must be taken to evaluate the computer-generated data. Therefore, field work is a necessity when using office-based techniques such as computer analysis. Computers can assist the field geologist, but they cannot replace him.

Relationship of This Study to Others

Bill Williams Mountain represents a fairly simple setting from an environmental viowpoint. Because of this, little can be said about many of the geologic topics outlined in Chapter IV. This does not imply that the geologic criteria presented in Chapter IV are irrelevant to proposed ski areas, but rather that the setting of Bill Williams Mountain is fairly simple. Other areas with more complex environmental and geologic settings would benefit from the type of approach presented in this thesis.

One drawback to the Bill Williams Mountain study was the limited interaction of the author with other scientists. Ideally, an environmental study of a proposed ski area would be done by a variety of different workers. Geologists, hydrologists, biologists, soil scientists,

and engineers could all be used to complete a study of this nature. Using people in different but related disciplines would insure a complete systems-wide study. Thus the possibility of overlooking any environmental impacts or constraints would be greatly reduced.

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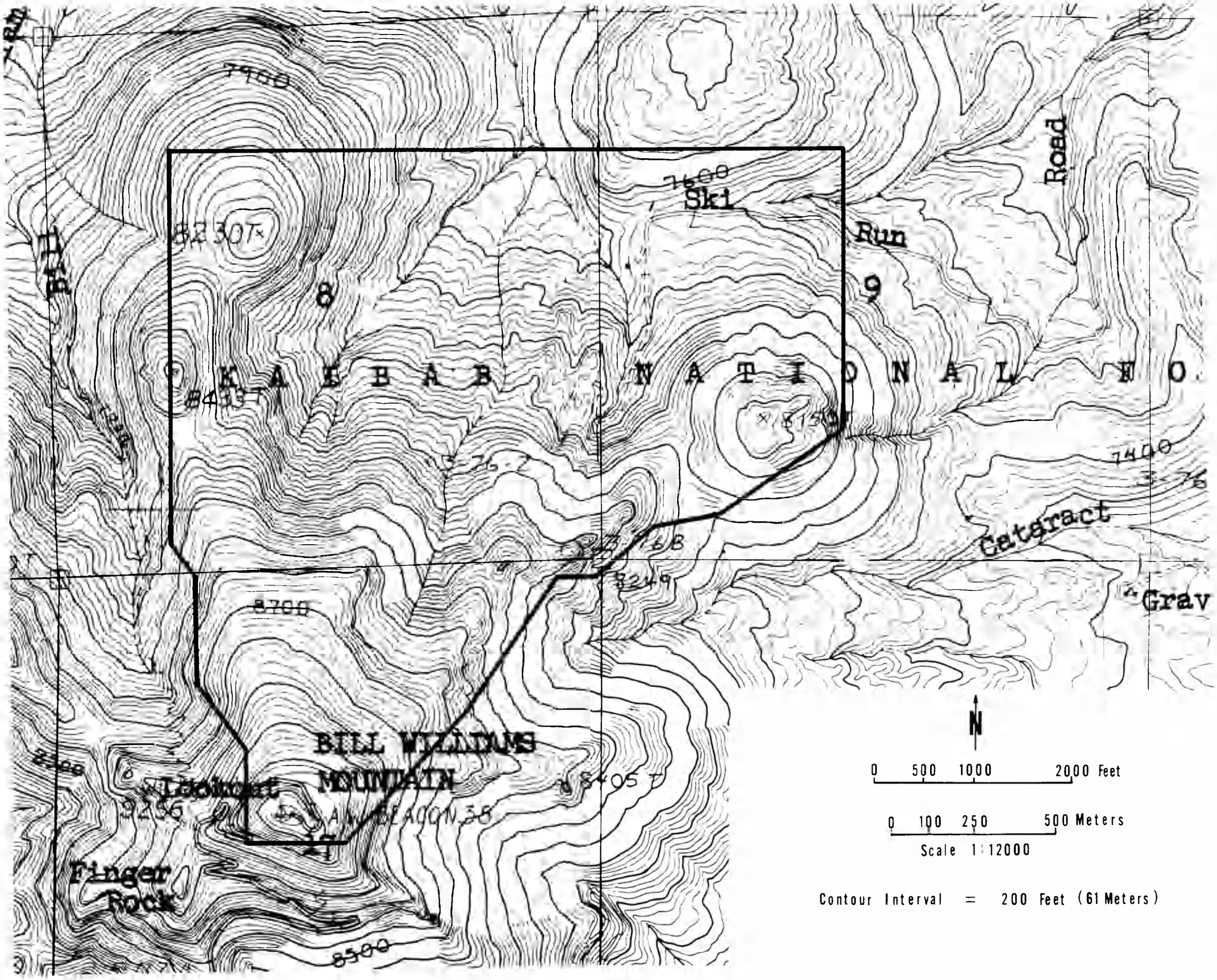

Figure 6. Location of Study Area on Bill Williams Mountain