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Multiple Hazard Research in Kananaskis Country, Alberta: A Geographical Information System Approach

By

Alastair J. Small
B.Sc. (Hons), University of Strathclyde,
Glasgow, 1989

Thesis

Submitted to the Department of Geography
in partial fulfilment of the requirements
for the Master of Arts degree
Wilfrid Laurier University
1992

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Abstract

This research is concerned with the application of Geographical Information System techniques to multiple hazard research in Kananaskis Country Recreation Area, southern Alberta. The study is focused on Peter Lougheed Provincial Park, a high mountain environment in the front range Rockies.

Increasing human activity in the area is putting more and more people at risk from natural hazards, thus the need for more efficient land use planning is evident. This research attempts to map and predict avalanche, forest fire, rockslide/rockfall, and flood hazard occurrence, and estimate the degree of risk associated with each. Data relating to the physical characteristics and human activity in the study area were obtained from a variety of sources, and stored in digital format under the common framework of the GIS.

Susceptibility maps are created for each hazardous process, which are then combined with data relating to human activity in the area, to provide an indication of the spatial and temporal patterns of risk. The research concentrates on the application of GIS to hazard research, rather than actual results of direct use to land use planning.

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And finally, to the great friends I have made while living in Canada. They know who they are.

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CHAPTER 1.

Introduction

1.1 Background and Purpose

This research is concerned with the application of geographical information system techniques to multiple hazard research in a high mountain environment. Much research has been done regarding the mapping and prediction of hazardous events in such an environment (Kienholz, 1978, 1983, 1984; Ives *et al.*, 1976, 1978, 1980; Fort, 1987; Gardner, 1981; Hestnes and Lied, 1980), but the application of GIS techniques to multiple hazard research is a relatively new approach.

The concept of natural hazards arises from the interaction of society with the environment. There would be no hazard were it not for humans being present. Therefore hazard research must not only investigate the physical processes occurring but also the human component involved. This society-environment conflict that gives rise to natural hazards, sometimes with devastating consequences (Anderson, 1968), is nowhere more prominent than in high mountain regions. Due to increasing activities in such mountain environments, the need for hazard research and its importance in land use management is foremost if natural hazards are to be mitigated.

The use of a geographic information system allows a wide variety of information from various sources to be input and analyzed efficiently and effectively (Bender and Bello, 1990). Most hazard research techniques up to now produce a "static" map of single or multiple hazards (Kienholz, 1978; Ives and Bovis, 1978; Rowbotham, 1984) which cannot be modified without having to change the map. The maps are generally "information rich" and at times hard to interpret, especially for non-specialized users. It is suggested that a main use of a GIS will be to provide a flexible database which can be expanded or updated through time, with many advantages over the "static" map. More complicated analyses can be performed; for example, to take into account seasonal effects, the ability to selectively illustrate the results by retrieving only what is required from the database, and the ability to model the consequences of new developments. In summary, the GIS has the ability to serve a variety of users, handle and analyze complex data and produce high quality cartographic output (More *et al.*, 1984). This powerful tool, combined with conventional methods of hazards research, provides the framework for an extremely flexible and effective approach.

The research is applied to Peter Lougheed Provincial Park in Kananaskis Country Recreation Area in southern Alberta (Figure 1.1). This high mountain region is well suited to the study due to the large amounts of data already available, and the fact that human activity is ever increasing. This activity is primarily in the form of recreational development (Kariel and Kariel, 1988), thus the need to study society-environment conflicts is essential if they are to be mitigated. The hazards looked at include avalanche, rockslides/rockfalls, floods and forest fires. Data were collected from the following sources: traffic analysis data; campground and trail usage; discharge records; surficial and bedrock geology, vegetation and topographic maps.

The format of this thesis is as follows; chapter one provides the background and purpose of the research, the objectives, and a brief outline of the of the study area. The theoretical review is covered in chapter two, where multiple hazard research, risk assessment, and the application of GIS in this field are examined. Chapter three is concerned with the physical characteristics of the study area and their influence on the hazardous processes being studied. These processes consist of avalanche, forest fire, flood, and rockslide/rockfall. Chapter four presents the methodology of the approach, with an introduction to the concepts of GIS, the data sources utilized, and their input, analysis, and output from the system. Errors and limitations involved with the data are also discussed. Chapter five illustrates the modelling results, with susceptibility maps produced for each hazardous process, and explanations of the criteria used in their production. Risk estimation is also performed, taking into account both the seasonal and temporal variation of hazards. Chapter Six contains the discussion and conclusions of the research.

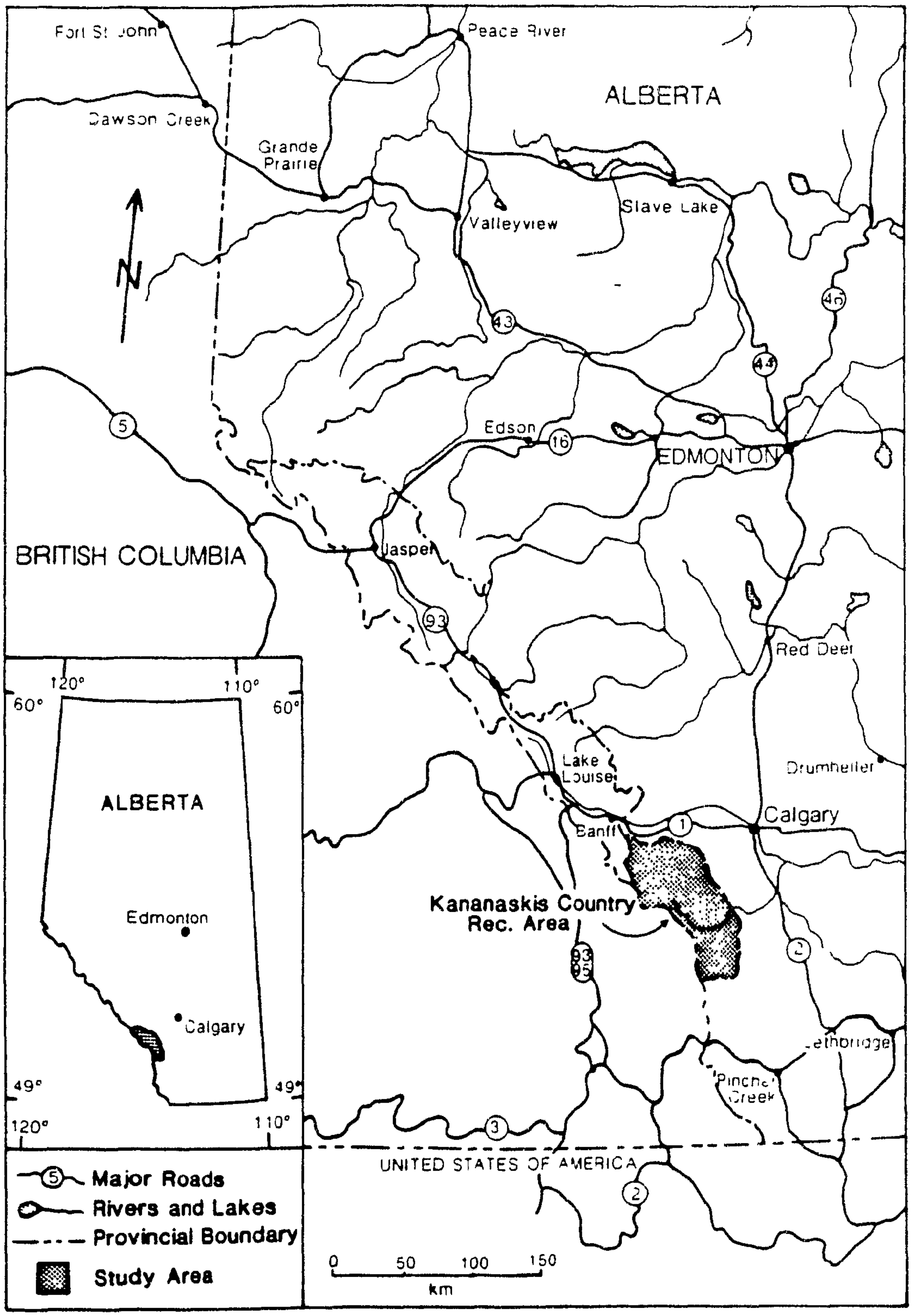

Figure 1.1: Location of Study Area

1.2 Objectives of Study

The objectives of this research are two-fold in character; in the first instance, to identify hazardous and potentially hazardous areas within the study area and estimate their degree of risk, and secondly, to assess the application of GIS techniques to multiple hazard research.

1.3 Study Area

This research applies to Kananaskis Country Recreation Area in southern Alberta (Figure 1.2). There are five main areas within Kananaskis Country;

1: Bow Valley Provincial Park
2: Ribbon Creek/Spray Lakes
3: Peter Lougheed Provincial Park
4: East Kananaskis Country
5: Highwood/Cataract Area

Of these, the research was concentrated within Peter Lougheed Provincial Park, due to the quality and quantity of data available. Kananaskis Country is a provincially owned and managed year-round, multiple use recreation area on the eastern slopes of the Rocky Mountains, adjacent to Banff National Park. It is 4200km^2 in area and contains a variety of vegetation, many species of wildlife and a diversity of terrain which lends itself to many recreational activities. Peter

Lougheed Provincial Park lies toward the north west extent of the park on the border with British Columbia, and its boundaries take in more than 500km^2 (Figure 1.3). Peter Lougheed Provincial Park is typical of high mountain areas that are continually and increasingly being used for recreational and economic development. This, coupled with the availability of a wide range of data in various formats, made this area ideal for the application and assessment of this type of approach.

Peter Lougheed Provincial Park ranges approximately from 50° 50' north to 50° 31' north and 115° 24' west to 114° 55' west. The Rocky Mountain Front Ranges represent most of the area, although a small portion of the Eastern Main Ranges occurs west of the Kananaskis Lakes. To understand better the physical processes involved in hazardous events, it is essential to look at the environmental conditions that are present. To give a better insight into the geomorphic activity and its relevance to natural hazard research in the area, an overview of the conditions which predominate in this area of the Rockies is discussed in chapter three.

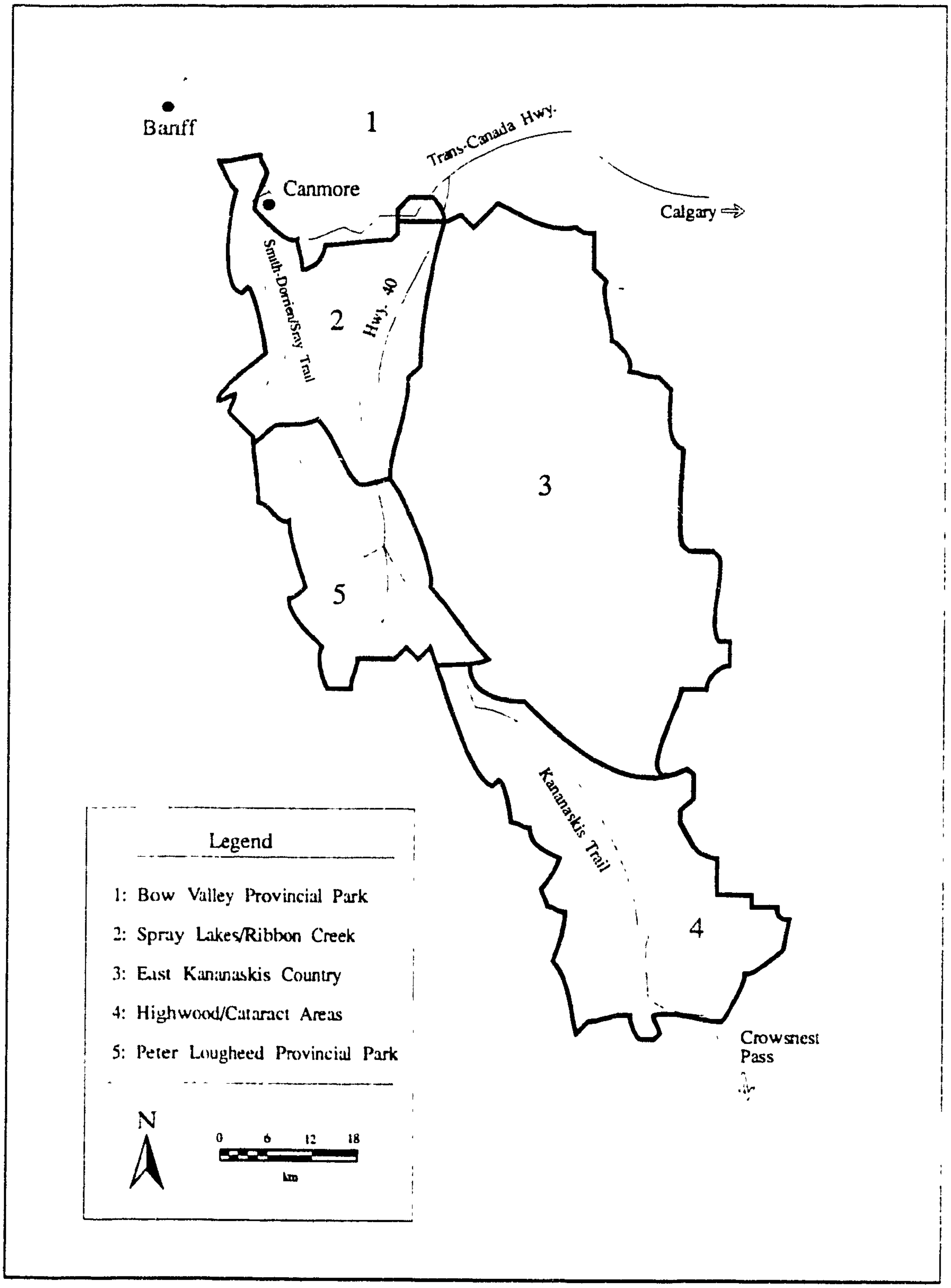

Figure 1.2: Kananaskis Country Recreation Area

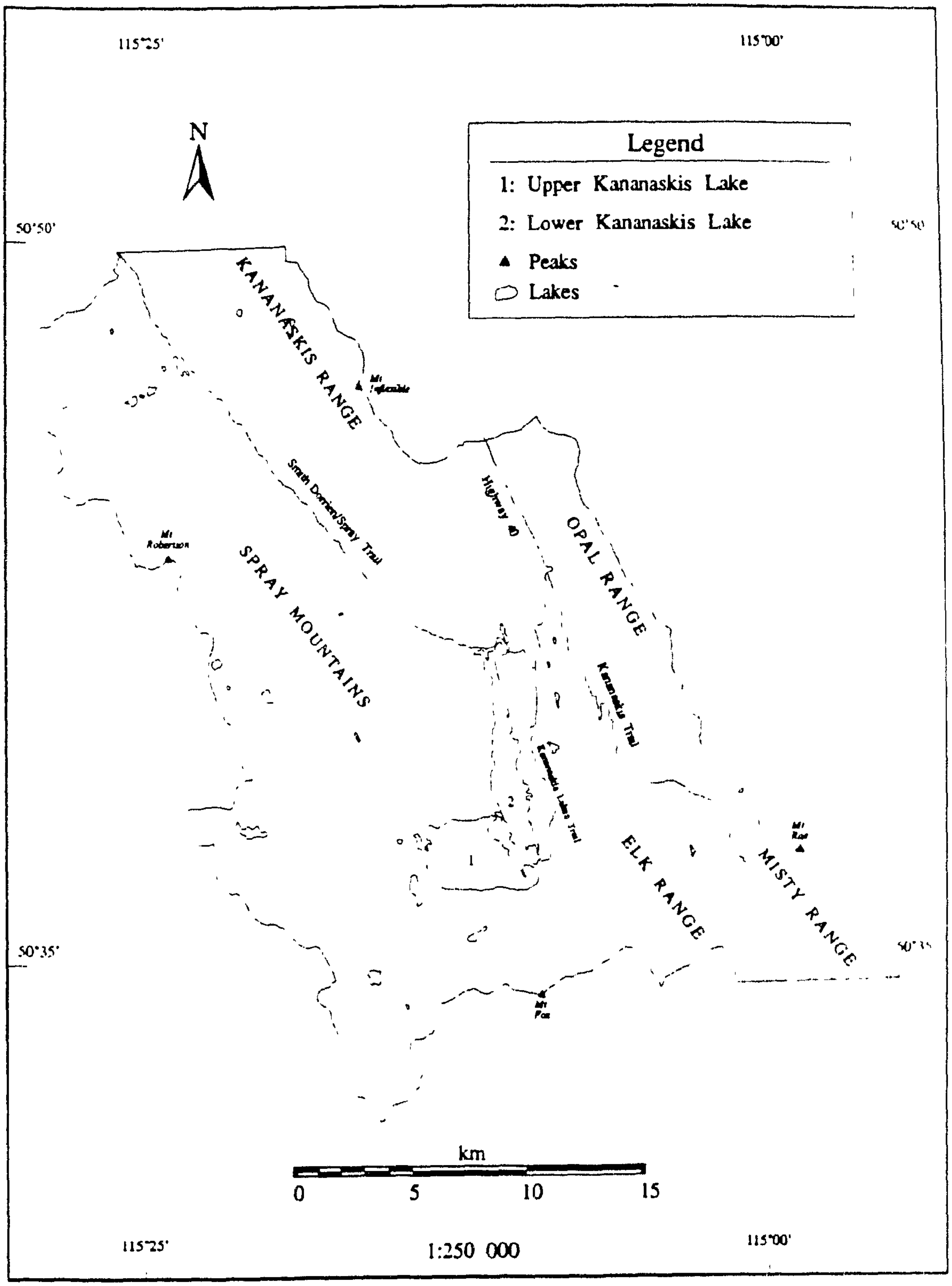

Figure 1.3: Peter Lougheed Provincial Park

CHAPTER 2

Theoretical Review

2.1 The Relationship between Society and Nature

The concept of natural hazards involves aspects of the relationship between society and environment. It is only when the interaction of the environment with human activity threatens to cause loss of life or property, or disruptions of individual or community routines or organizational structure that we see the environment as hazardous (Palm, 1990). Thus, a natural hazard of any sort is a function both of the physical event itself and of the state of human society (Hewitt *et al.*, 1971).

Economically, socially, or biologically adverse interactions between society and the environment constitute what are considered natural hazards. Most commonly it is some potentially damaging process or condition in the natural system that is identified as 'the hazard'. However, when damage occurs, it is largely as a result of poorly planned or over-exploitive use of the physical environment. Of course, a society's relationship to its habitat has both positive and negative aspects (Hewitt *et al.*, 1971). The positive aspects may be defined in terms of 'natural resources' which are utilized for productive or amenity purposes. The negative aspects are the loss and damage that are caused by natural hazards.

In terms of the qualities or measures of natural processes, there is no sharp division between these two aspects, but there may be thresholds at which the beneficial consequences are outweighed by losses. Where these thresholds occur, however, is as dependent on society as the process itself. It is the structure of society that permits or even amplifies the effects of normal climatic, geophysical or biological activity, sometimes converting expected variability into what becomes a "disaster". For example, economic developments can increase vulnerability to fluctuations in rainfall; a permanent residential use of a floodway obviously increases vulnerability to flood-related damage, compared to other land uses in which fewer people would risk loss of life and property (Palm, 1990).

In so-called 'developed' countries, technology nevertheless leads to changes in societies relation to its habitat at an ever increasing rate. Roelofs *et al.* (1974) suggest that a technologically "advanced" society perceives itself as a conqueror of nature. Heavy emphasis is placed on technical control and modification of the hazard itself. But sometimes that involves negative consequences, and a new class of hazard is being identified with advances in technology, that of technological hazards. Examples of technological hazards include air and water pollution, acid rain and toxic waste disposal. However, the present research primarily focuses on natural hazards.

From the above it is seen that to research natural hazards successfully, for example, to define better land use management with respect to natural processes, it is essential that we look at both the physical and human components involved. This approach constitutes the paradigm of natural hazard research.

2.2 Risk Assessment

The word "risk" has been used in the literature to mean either the probability of danger, or the hazard itself. Whyte and Burton (1980) use risk to mean a hazard or danger with adverse consequences for society of a certain probability of occurrence or probabilistic range of occurrence.

Risk assessment is a broader term that encompasses the process of identifying the hazards, estimating the threat they pose to humanity, and evaluating such risk in a comparative framework (Kates, 1970). Thus, risk assessment is an appraisal of both the kinds and degrees of threat posed by a hazard (Kates, 1978) and consists of three elements: hazard identification, risk estimation and social evaluation.

Hazard identification is concerned with the interaction between the environment and society, in order to determine the products, processes, phenomena and persons that constitute hazards, posing a threat to man and nature. For the most part it depends on evidence of past damages or damaging events. Risk estimation seeks to scientifically determine the nature and level of the risk involved, usually from an analysis of known occurrences over time and space. Sometimes, in rapidly changing situations, it is necessary to estimate likely new levels or types of risk. Social evaluation involves the significance attributed to the measurement of threat potential.

While these three elements of risk assessment overlap considerably both in theory and practice, each remains a distinctive element. In practice, risk assessment often begins by looking at one part of the problem, usually the source or the effect, rather than considering the system as a whole (Whyte and Burton, 1980). Once a risk is suspected, it is important to bring together as much available information as is possible before designing ways in which additional data are to be collected.

Kates (1978) examines the limitations of these three elements of risk assessment, in order to illustrate the problems encountered with such a methodology. Numerous complications are inherent in risk estimation, for example, relating effect to their causes or deciding whether experimental findings are significant. Balancing or comparing consequences of hazards may depend upon a standard database, which as yet is internationally unavailable. In a changing context, if there is no mechanism or generic principle that can predict hazardousness without first experiencing it, we may find we rely on methodologies that are unreliable, costly or biased.

Lowrance (1980) has identified other problems in risk assessment, for example scientific uncertainty and the criteria of cost-benefit analysis. Scientific uncertainty reflects the current inability of science to predict the timing, magnitude and social distribution of risk associated with natural hazards. Keenay and von Winterfeldt (1986) have related this issue to the problems of risk communication. The issue of assigning cost and benefits in any kind of standard currency to environmental hazards has been noted, and is largely due to the problem of multiple and competing objectives or culturally determined expectations.

After the risk has been assessed, there comes a point where intervention or decision not to intervene takes place (Whyte and Burton, 1980). Depending on the nature of the risks and political economy of the society involved, the decision and nature of intervention varies widely. Lowrance (1980) notes the absence of absolute guidelines concerning the extent to which any authority should intervene in order to mitigate natural hazards.

Despite many of the limitations associated with risk assessment, it can be seen as an important and integral part of natural hazard research. And while it may not be the job of the geographer, but of the political system, to make the decisions regarding what is acceptable risk, what must be provided is a model that can be modified according to different policies and socio-economic change, in order to effectively assess risk. It is suggested that the use of geographical information system techniques will enhance this process, primarily in the estimation stage.

2.3 High Mountain Hazards

"To focus research on mountainous regions is, presumably, to recognize that they define a distinct and meaningful area of specialization" (Hewitt, 1988). One favoured approach of organizing the subject matter of geography is by "natural region". Although still significant in certain fields of geography (e.g. soil, agricultural geography), it has fallen into disrepute as a means of organizing human geographic study mainly because of the strong associations with environmental determinism. The problem with this approach is the failure to deal adequately with the human dimensions of mountain areas.

As already noted, natural hazards are largely a result of conflict between humans and environment, therefore we must recognize the need for an approach that takes into consideration both the human and habitat component of the geographical region. The physical characteristics of the region can be analyzed to successfully delineate hazard prone areas. That is, areas where conditions occur known to cause damage under various types of human use, and these hazardous natural conditions can be subsequently measured and analyzed (Chouby *et al.*, 1990). This is an essential first stage in hazard research, but in order to recognize the human component and perform risk assessment, the same must be done for human response to hazardous events. This involves integrating socio-economic data with the hazardous areas delineated.

Recent mountain research tended to take a mainly geoecological approach, explaining the unique characteristics of the rugged and high elevation environment. There is often a lack of research on the human geography of mountain regions. Soffer (1984) suggests two reasons for this: firstly, the major thrust in human geography has been in the urban field, with a tendency to regard mountains as being the backward or romantic regions of the world; secondly, the lack of a study unit in human geography. That is, the classification of mountain systems has generally been done by climatologists, geomorphologists or geologists, and these definitions do not suit the purpose of regional geography. What is required is a combination of techniques that takes into account both the physical characteristics of the region and also the human dimension present.

Conditions which can threaten life and property are widespread in mountainous areas due to the various topographical and climatological regimes that are present. Great physiographic and climatic diversity are as much a part of the problem as specific conditions like steep slopes, rapid runoff, cold or altitude. Thus a wide range of hazards may be experienced ranging from large scale-low frequency events such as large earthquakes to small scale-high frequency events such as rockfalls. Any mountainous region is geologically active and has high rates of denudation. Exceptionally steep slopes and rugged terrain are the primary cause of such geomorphic activity.

Mountainous regions, such as Kananaskis Country Recreation Area, are experiencing accelerating pressures from rapid development of industry and recreational activities (Ives *et al.*, 1976, Kariel *et al.*, 1988). In this case it is principally winter sports expansion and the spread of second homes. These socio-economic factors often bring large numbers of people with little or no mountain experience in high mountain terrain. Superimpose this level of activity on the topographic and climatic setting and it becomes readily apparent that conditions exist for a potentially hazardous situation.

People whose life style, technology, and expectations have developed outside mountainous areas are more susceptible to hazards when they enter into the mountains, as much due to the alien environment as specifically mountain risks. It has been noted by Allen (1984, 1986) that most, if not all, of the major problems today are triggered and shaped by developments outside the mountains. Hewitt (1986) notes that linkages with outside areas are significant in such problems as deforestation, accelerated erosion and "over population", stating that the initiative here is with outside socio-economic forces rather than mountain geoecology. A lack of understanding of the physical processes contributing to natural hazards and of their temporal and spatial nature often leads to improper land use planning and management. This, coupled with inadequate building codes and restricted information availability, can have disastrous consequences.

Previous hazard research in mountainous areas has attempted to address the physical and human components involved with varying degrees of success. Rowbotham (1984) states that in order for a degree of risk to be meaningful, the terms of reference for the evaluation must be defined. The failure of Dow *et al.* (1981) and Panizza (1978) to define their terms of reference places a serious limitation on the practical value of their research. Hestnes and Lied (1980) classified areas as safe or not safe for development, but which types of development were not specified. Ives and Bovis (1978) also only define the degree of hazard in terms of building structures.

Kienholz (1978) on the other hand, defines precisely the degree of risk in terms of structures with a life expectancy of 100-150 years. Soule (1976) suggested the idea that an area might be used for different activities by producing a matrix to illustrate the degree of risk relative to the type of land use. Others noted that this technique was good in theory but impractical to carry out. However, this is the type of analysis that is efficiently carried out using a GIS system, and provides an effective approach to risk assessment.

One main factor not addressed in hazard research by geographers is the temporal aspect of hazard occurrence, whereas it has been the main style of assessment in other fields, for example geophysics, hydrology, and storm forecasting, which pay less attention to spatial distribution of risk. The majority of research produces a static map which often portrays risk calculated from frequency calculations of hazardous events. The use of GIS allows for constant updating of frequency and magnitude data for various events, and also allows us to address the seasonal nature of risk from both the physical and human components in an effective manner.

2.4 Hazard Research and GIS

The use of Geographical Information Systems in hazard research is a fairly new approach with little research having been done to date, (Brabb, 1987; Bender and Bello, 1990). In order to utilize the large and disparate sources of data in hazard research efficiently, it is obvious that new techniques are required for obtaining, processing, and displaying spatial information in a timely and cost-effective manner. According to Chuvieco and Congalton (1989), this is the main objective of a GIS approach. A GIS takes advantage of the computer's abilities to store and process great volumes of data (Burrough, 1987). Therefore, it makes it possible to update and retrieve spatial information, as well as derive cartographic models by combining, in different ways, the layers of information included in the data base.

Geographic Information Systems have been successfully used in Latin America and the Caribbean to assist development planners in natural hazards assessments. Individual and multiple hazards analysis have been combined with information on natural resources, population and infrastructure using PC[1]-based technology to assess vulnerability of sectoral development projects as well as to support emergency preparedness and response activities (Bender and Bello, 1990). Applications have been carried out at the national, regional and local levels. Bender and Bello (1990) note that manual approaches were once used for this purpose, but the volume of information needed for natural hazards management, particularly in the context of integrated development planning, makes a compelling case for the use of computerized techniques.

Chuvieco and Congalton (1989) studied the application of GIS to forest fire hazard mapping, stating that it is one of many appropriate GIS applications. The diversity of factors that affect the beginning and spreading of a forest fire dictates the use of an integrated analysis approach. The objective of this project was to establish a reliable method for fire hazard mapping in a mediterranean environment. Chuvieco and Congalton (1989) conclude that an integrated analysis of spatial variables is valuable for forest fire research, with the use of GIS processing making it possible to create fire hazard models.

The Natural Hazard Risk Assessment and Disaster Management Pilot Project (NHP) identified as an important area for experimentation, the use of GIS and computer aided natural hazards risk assessment and mapping (Bender and Bello,

[1] Personal Computer.

1990). Five years of experience and close to 200 maps covering a broad variety of geographical settings, natural resource endowment, population density, and natural hazards in more than 20 countries in Latin America and the Caribbean has given NHP valuable insights as to how, where, and when to use this technology for hazards management. Bender and Bello (1990) base the contention that GIS can be beneficial for planners on a number of facts. First, a GIS provides a powerful analytical tool that is now available at relatively modest cost. Second, the main constraint to the use of GIS in planning agencies is commonly not the lack of funds, but lack of trained personnel. Third, GIS can multiply the productivity of a technician and so reduce costs, and fourth, use of GIS can give higher quality results than manual techniques, regardless of costs involved.

Natural hazard mitigation can best be implemented through development planning studies. GIS plays a crucial role in this process, serving as a tool to collect, organize and analyze data, and as the means of providing the information needed. Altogether, information on natural hazards, natural resources, population and infrastructure serves as baseline data in the GIS for hazards management. Bender and Bello (1989) suggest that the GIS be used at various levels of development planning, at the national level to provide general familiarization with the study area, at the regional level for resource analysis and project identification, and at the local level planners can use a GIS to formulate investment projects and specific mitigation strategies for disaster prevention activities.

Based on the experience of NHP, it is possible to outline a number of conclusions about the application of GIS in hazards management in Latin America and the Caribbean. First, GIS can improve the quality and depth of natural hazards assessments, guide development activities, and assist planners in the selection of mitigation measures and implementation of emergency preparedness and response actions. Second, use of GIS to combine and analyze readily available information on natural hazards, natural resources, population, and infrastructure, can uncover valuable vulnerability information. Third, simple and affordable equipment can be as effective as the large expensive systems, especially for the purposes of map analysis for hazards management. Finally, use of GIS is clearly more advantageous when these systems are used not only for hazards analysis, but also for a wider range of activities related with integrated development.

2.5 Multiple Hazard Research as a Land Use Planning Tool

Most multiple hazard research is carried out with this applied aspect as its objective (Bender *et al.*, 1990; Hestnes *et al.*, 1980; Ives *et al.*, 1989). In order to successfully mitigate the risk from natural hazards, the information from hazard research must be utilized by decision makers and land use planners. Ives *et al.* (1978) states that the research results must be translated into meaningful recommendations so that the responsible decision-makers can improve mountain land management within the limits set by the democratic process of local government.

The main centres of research are in Europe and North America, with notable work also carried out in Japan (Kanankubo and Tanioka, 1980). North America has not experienced the same degree of human pressure in its alpine areas as Europe. However, the same trends are evident. Notable studies that have been carried out are by Kienholz (1978), Hestnes and Lied (1980), Dow (1981) and Ives *et al.* (1976, 1978). One of the main areas of concentration is in the State of Colorado, where the Colorado House Bill 1041 passed in 1974, requires each county to prepare geologic hazards maps.

Similar legislation exists in Norway, where the Norwegian National Building Code states "ground can only be built on if there is sufficient safety against subsidence, inundation, landslides, etc." This implies that areas which are not obviously safe should be regarded as insecure until an evaluation of natural hazards has been accomplished (Hestnes and Lied, 1980).

Ives *et al.* (1978) suggests that identification of mountain areas subject to a variety of natural hazards and research aimed at understanding the release processes and recurrence intervals involved will remain as esoteric exercises unless adequate steps are taken. These are first: to achieve proper communication between researcher and planner and second: to ensure direct input into the decision making process at the local township and county levels.

Development in the Rockies has resulted in the creation of "instant" resort towns, for example Vail, where conditions exist for potentially hazardous situations. The problem becomes the more intractable in those instances where no prior zoning regulations exist, and a free-market system prevails where developers are not mountain people with any inherent knowledge of the basic instability of much of the area undergoing construction (Ives *et al.*, 1978). Hewitt (1986) notes that it is with outside socio-economic forces rather than mountain geoecology, that most of the problems occur today. The Institute of Arctic and Alpine Research (INSTAAR) has been seeking to develop methodologies, including a combination of remote sensing techniques and interdisciplinary field studies, to assist governmental agencies at the township, county and state levels to alleviate this serious land use management problem (Ives *et al.*, 1978).

Ives *et al.* (1978) note that as mountain population centres expand, human beings and private and public property impinge ever increasingly on areas subject to natural hazards, thus the potential for disaster grows. It is this potential contact between natural events and humans and their developments that constitutes the definition of natural hazard in the broadest sense. For land use decision making, a more detailed definition than this is required, encompassing size and frequency of the events in question, as well as magnitude of impact pressures.

CHAPTER 3

Physical Characteristics

This chapter discusses the physical characteristics of the study area, and their relation to hazardous processes. An overview of the geology/topography, climate, hydrology, and the vegetation is presented, leading to a more detailed discussion of how they may influence avalanche, forest fire, flood, and rockslide/rockfall hazard.

3.1 General Characteristics

3.1.1 Geology/Topography

The area is underlain by sedimentary strata deposited on Precambrian basement rocks (North and Henderson, 1954). During the Laramide orogenies the sediments were deformed and uplifted through folding and extensive thrust faulting. The large scale elements of the topography of the area are controlled by geological structure. A NNW-SSE trend of major valleys and ranges is representative of the front ranges in general and indicates the presence of several major thrust faults and fault blocks (Gardner *et al.*, 1983). The predominant strike of the region is 20° to 30° west of north. Thrust planes and strata dip steeply towards the west. Other prominent structural features of the area include minor but spectacular folding and oblique faults which trend in a northeast to southwest direction. Transverse faulting and glaciation result in deviations from the general NNW to SSE trend, with long, relatively steep concave valley profiles, extensive cirque formation along ridge crests, and tributary valleys and gorges.

Frequency calculations were performed on elevation, slope, aspect, and geological data. Figure 3.1 illustrates the elevational distribution within the park, with the largest percentage of the area lying in the mid elevation bands between 1900m and 2500m. The mean elevation of the area is 2200m. Figure 3.2 illustrates percentage distribution of slope, with a large percentage of low to mid gradient (10 to 30 degree) slopes. The mean slope of the area is 21°. It can be seen clearly from analyzing the relationship between slope and elevation, that the steeper slopes (>30 degrees) are more abundant above 2500m. Aspect distribution is shown in Figure 3.3, which reflects well the nature of the structural geology. The general NNW-SSE trend of valleys created by structural control leads to the large percentage of NE and SW aspect in the area. This is representative of the scarp and dip slopes of fault blocks (Gardner *et al.*, 1983). Slope aspect plays a significant role in creating special micro-environments in the high mountain context. This, in turn, leads to marked contrasts in geomorphic processes, types and intensities, on slopes of different aspects.

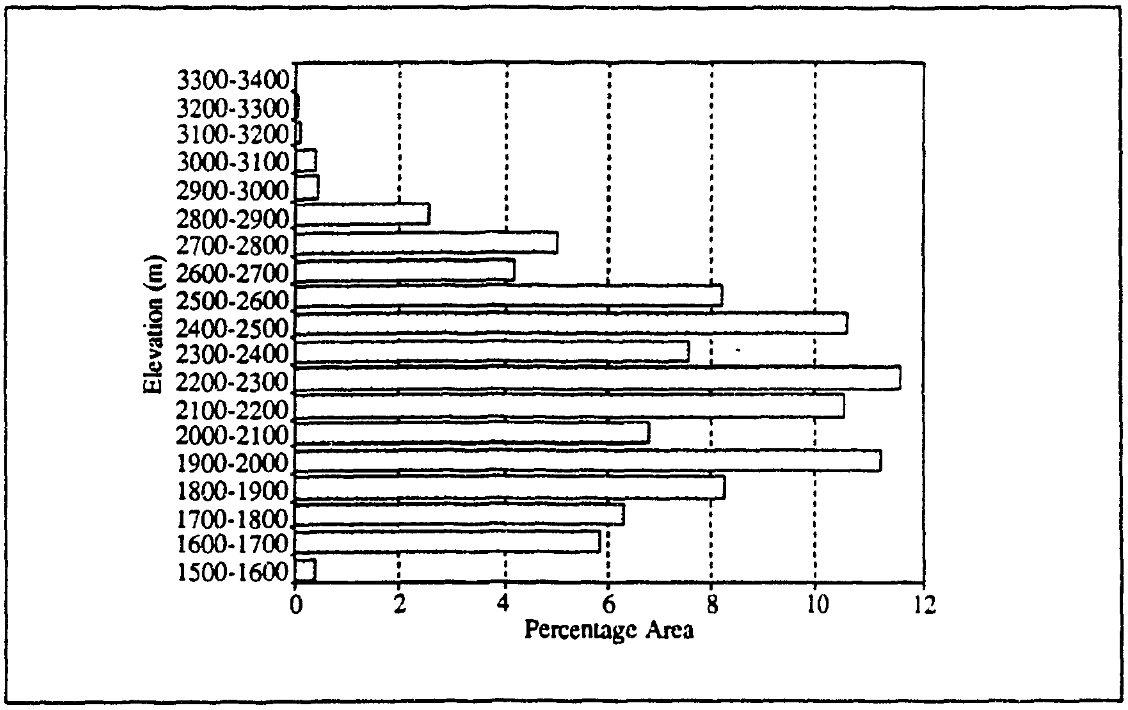

Figure 3.1: Elevational Distribution

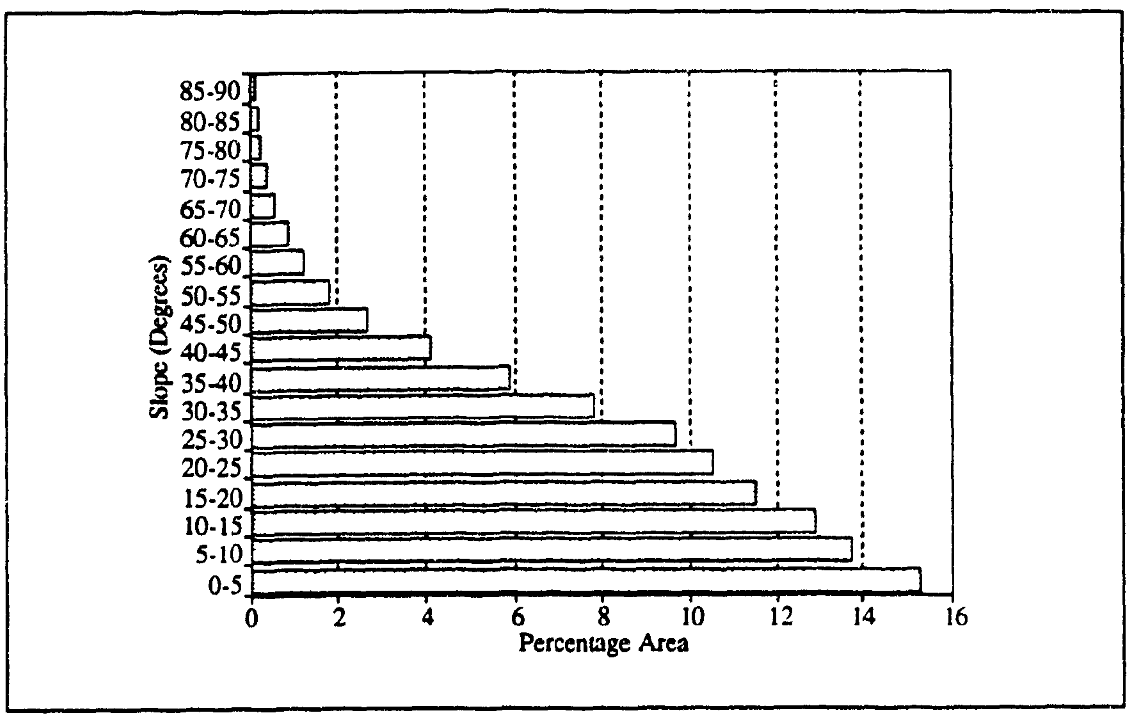

Figure 3.2: Slope Distribution

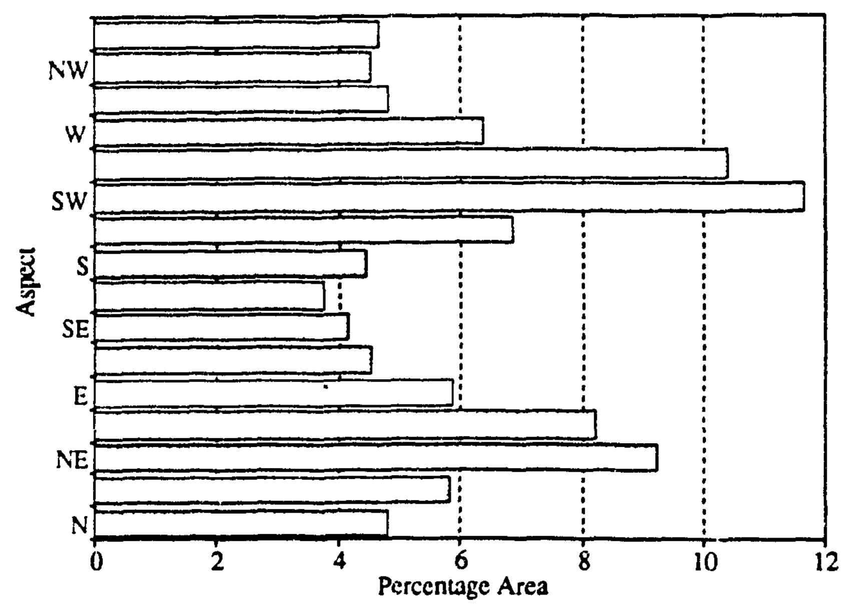

Figure 3.3: Aspect Distribution

Surficial geology is represented by alluvial (3%), colluvial (55%), glaciofluvial (2%) and morainal (16%) deposits, and exposed bedrock (24%). Morainal deposits are most prominent in the lower elevation bands, between 1500m and 2000m, colluvial deposits in the mid elevation bands, between 1800m and 2300m, and exposed bedrock in the upper elevation bands, above 2200m. Exposed bedrock has a strong relationship with aspect, with a high percentage (65%) of these areas having north easterly and south westerly orientations. This, again, reflects well the structural geology of the area. Morainal and colluvial deposits, which are prominent in the lower elevation bands, have no distinct orientation. Bedrock outcrops on steeper slopes of course, particularly on scarp and dip slopes, with gradients over 30°.

Bedrock geology is classed under the following rock formations: Cadomin, Kootenay, Fernie, Spray River, Spray Lakes, Rundle, Banff, Palliser, Fairholme and Yahatinda. Spray River (17%), Spray Lakes (12%), Rundle (20%), Banff (14%) and Palliser (13%) constitute the largest percentage of formations in the area. The Palliser formation is the oldest exposed strata, consisting primarily of resistant light grey dolomites. The Banff formation, in comparison with underlying and overlying formations, is less resistant to erosion (Douglas, 1958) and in the study area forms narrow, talus covered valleys. The Rundle group is the most prominent stratigraphic unit of the study area, constituting the major cliff-forming strata in the Misty, Elk, Opal, Spray, and Kananaskis Ranges, of which the Mt. Head formation is of particular interest because of its cliff-forming members which have been the prominent points of rock slope failure. Kootenay, Fernie, Fairholme and Spray River formations are more prominent in the lower elevation bands, between 1600m and 2200m, whereas Cadomin, Palliser and Yahatinda more so in the mid elevation bands, between 2100m and 2600m. In the upper elevation bands, 2300m and above, it is the Spray Lakes, Rundle and Banff formations that are more abundant.

3.1.2 Climate

Climatically the area is a transitional one, between the Cordilleran and Prairie regions. It experiences a cold subhumid continental climate, characterized by long cold winters, modified by short periods of comparatively warm, dry chinook conditions and short cool summers (Kirby, 1973; Hillman *et al.*, 1978). On the macro-climatic scale, the area is controlled by three air mass types: Polar Continental, Pacific Maritime, and Tropical Maritime (Gardner *et al.*, 1983). The dry, cold polar continental air dominates in winter time, whereas the spring and early summer season is marked by the transition from the predominantly polar air mass to a modified pacific air mass (Rhuemer, 1953).

Because of the mountain-induced elements of altitude and topography, macro-climatic patterns are often modified by local meso- and micro-climatic controls, typical of any mountainous location. Barry *et al.* (1974) noted that local climatological patterns result from the interaction of local exposure, topography and relief, with the prevailing regional meteorological controls. The analysis of climatic data is made difficult by the spatial and temporal variabilities which develop, in addition to the lack of climatic records in the study area.

3.1.3 Hydrology

The hydrography of Peter Lougheed Provincial Park is shown in Figure 3.4, comprising a single drainage basin of approximately 600km^2. The gauging stations for which discharge records were obtained are listed below, and locations illustrated in Figure 3.4:

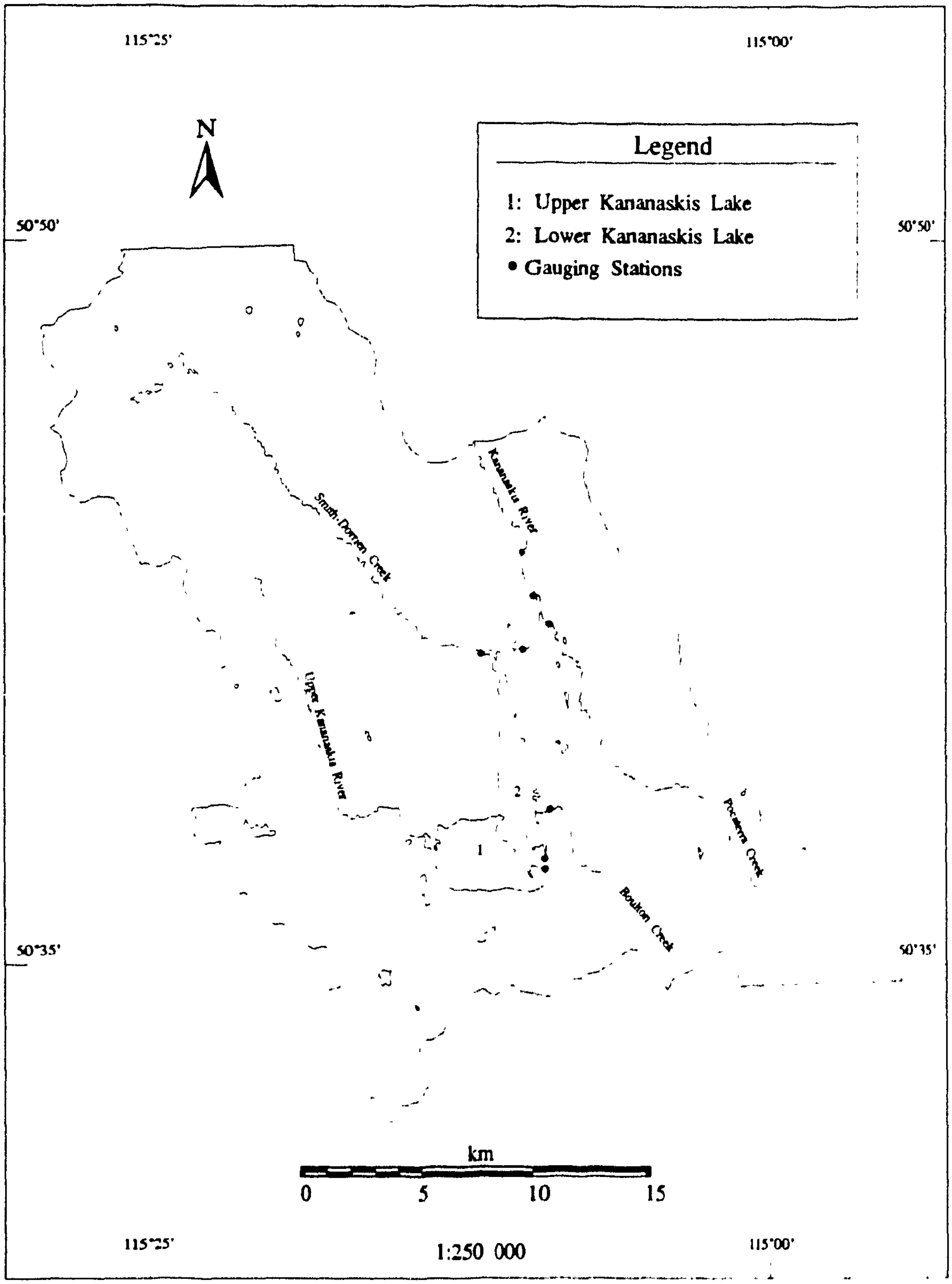

Figure 3.4: Hydrography and Gauging Station Locations

Gauging Station Name:	I.D. Number:	Operation
1: Kananaskis River above Lower Lake	05BF002	1931-35
2: Kananaskis River at Pocaterra Creek	05BF003	1931-86
3: Kananaskis River at Canyon	05BF022	1933-35
4: Kananaskis River at outlet of Lower Lake	05BF010	1932-48
5: Boulton Creek near mouth	05BF011	1936-41
6: Pocaterra Creek near mouth	05BF004	1931-41
7: Smith-Dorrien Creek near mouth	05BF008	1932-33
8: Upper Kananaskis Lake (level station)	05BF005	1932-86

The area is a source region for several front range and foothill rivers, with Kananaskis River serving as a major tributary to the Bow River. The main streams within the study area are Smith Dorrien Creek, Boulton Creek, Pocaterra Creek, Upper Kananaskis River and Kananaskis River. Average discharge for selected stations, based upon daily measurements, is shown graphically in Figure 3.5, with peak flows occurring in the snowmelt period of May, June and early July, typical of a nival regime. In addition to the continuously flowing streams, there are also a number ephemeral or intermittent streams in the area. These flow only during and shortly after the snowmelt period, usually every year (Gardner *et al.*, 1983). The upper limit for continuously flowing streams is around the 2700m elevation, but ephemeral or intermittent streams may well occur at higher elevations. Continuously flowing streams do not appear to occur on slopes in excess of 40°. Upper and Lower Kananaskis Lakes are the largest lakes in the area with a combined area of nearly 15km^2, and are drained by the Kananaskis River.

Snowcover is one of the most significant components of the hydrology of the

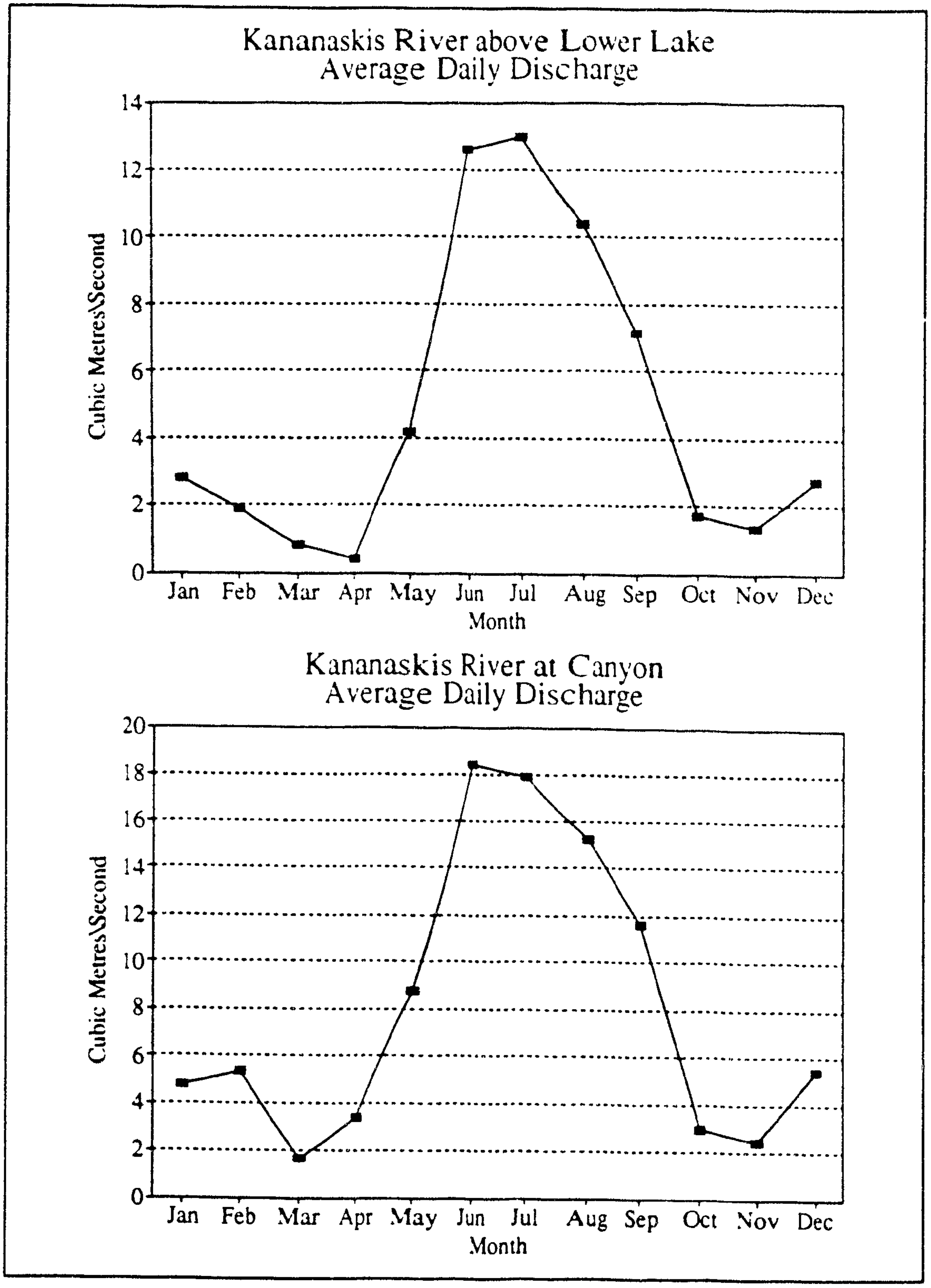

Figure 3.5: Discharge for Selected Stations (based upon daily measurements)

area (Gardner *et al.*, 1983), and also an important factor in the present geomorphic characteristics of the area. Its distribution is spatially and temporally variable in the region, being influenced by a variety of climatic, topographic and vegetative factors. Much of the water from melting snowcover infiltrates into surficial deposits of glacial and mass wasting origin, before reappearing in streams. This high infiltration capacity causes a lag in the onset and duration of melt-related flows and is thus important given that steep slopes would otherwise promote very rapid runoff. Thus mass wasting deposits perform a significant hydrological function in the area.

3.1.4 Vegetation

Vegetation plays an important role in the geomorphic environment. For example, plants act as buffer against erosional processes in most cases, notably through increasing infiltration and providing a micro-climate that lends itself to reducing the rate of snowmelt. Conversely, trees which are uprooted and displaced in avalanches may accelerate erosional processes. Vegetation distribution can also be used as an indicator of hazardous processes, by spatially and temporally referencing certain events. For example, in the case of identifying avalanche tracks to indicate spatial distribution, collecting tree ring data to provide the temporal aspect (Potter, 1969), or in the case of forest fires which provide both temporal and spatial indicators.

The study area lies within the subalpine forest belt of Alberta. With increasing altitude the major zones are: lower montane forests, forest-tundra ecotone, alpine tundra zone, and relatively sterile high altitude rock barren. Vegetation is classed into 45 different categories, and can be grouped under the main types of coniferous (38%), deciduous (1%), tall shrub dominated (1%), low shrub dominated (2%), herb dominated (1%), and alpine (8%), with the remaining 49% sparsely vegetated. Elevational distribution of sparsely vegetated areas, coniferous and alpine vegetation, collectively representing two thirds of the study area, are illustrated in Figure 3.6. As would be expected, the lower and mid elevation bands contain most of the vegetation, with coniferous forest present between 1500m and 2500m, and alpine vegetation between 1900m and 2600m. Sparsely vegetated areas become increasingly abundant above the 2200m level.

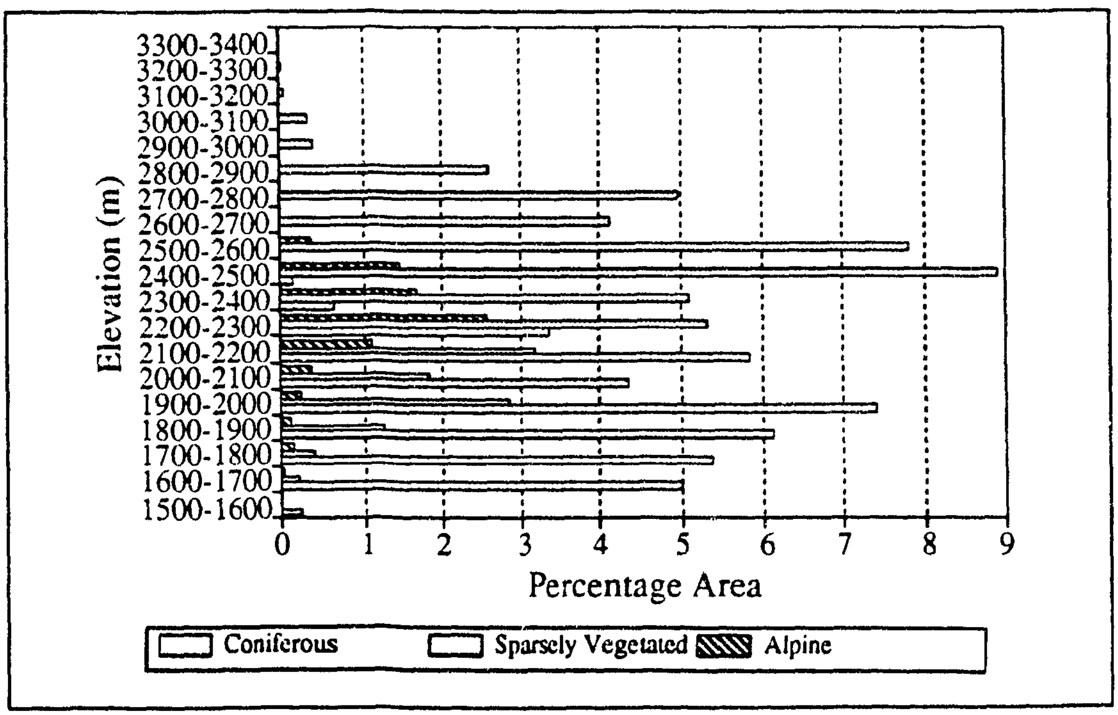

Figure 3.6: Elevational Distribution of Vegetation

3.2 Hazardous Processes

This research focuses on avalanche, forest fire, flood, and rockslide/rockfall hazard. These processes give a good cross-section of the type of hazards occurring in such an environment, and are the most common in the Canadian Cordilleran environment (Gardner, 1981). An understanding of the spatial and temporal distribution of these hazards is the initial stage in the prediction process.

Topography and climate are the environmental factors noted to be most relevant to avalanche hazard, while vegetation plays a subsidiary role (Gardner, 1981). The topography of the study area has significant influence in snow accumulation and avalanche activity, with relatively steep valleyside profiles, ideal for avalanche initiation and maintenance (Gardner, 1981). Over much of the study area, the topography is favourable to avalanche activity, with exceptions found in the valley bottoms, and on very steep scarp slopes where the gradient is too high to permit the accumulation of sufficient snow for avalanche generation (Gardner, 1981). Elevation is a topographic characteristic which influences avalanche activity to some degree through climatic conditions, notably lapse rate. The mean elevation of the area is approximately 2200m, which is slightly above climatic treeline, but well below permanent snowline. Nevertheless, a snowcover is maintained at this elevation and above for a least six months of the year (Gardner, 1981).

Climate is a dynamic element in avalanche occurrence, being strongly influenced by topography, especially at the local level. Approximately 60% of the annual precipitation in the area falls as snow, mainly in the winter period, but large snowfalls are common in nearly all months of the year (Storr, 1973). Snow begins to accumulate at higher elevations by early October, gradually increasing in depth until mid May (Gardner, 1981). In Kananaskis Country, the redistribution of fallen snow by wind is extremely significant for avalanche evaluation. It is common to see southeast-facing slopes (dip slopes) completely eroded of their snow cover in mid-winter (Gardner, 1981). Steep, northwest facing scarp slopes, do not generally accumulate large quantities of snow, but they do experience cornice building along their crests, which may pose a serious avalanche threat during late winter and spring (Gardner, 1981).

Vegetation plays a secondary role in avalanche hazard (Gardner *et al.*, 1983) which can both enhance snow cover stability and instability. Forested areas tend to stabilize snow cover on slopes, thus reducing the probability of avalanche release, although grass cover on steep slopes can increase probability by providing a sliding plane. Lack of avalanche occurrence at lower elevations can be directly related to more dense vegetation at these altitudes.

The area has had a varied fire history and few locations have not experienced some forest fire activity in the past century (Hawkes, 1979). During the past twenty years, the area has undergone selective clear cutting, and in conjunction with the fire history, has produced a forest cover of extremely varied stand age (Gardner *et al.*, 1983). Chuvieco and Congalton (1989) define fire hazard as a measure of the fuel sources available for ignition, whereas fire risk models include ignition sources as well as fuel sources. Fire hazard is influenced by a number of variables, mainly vegetation, elevation, slope, aspect, insolation, and climate. These are critical factors in any fire hazard rating system (Deeming *et al.*, 1978: Calabri, 1984: Artsybashev, 1983). Other factors also influence the vegetative cover, for example, hazardous processes such as avalanche and rockfall/rockslide.

Thus, a combination of natural processes and human interference with the environment, provide for diverse spatial and temporal patterns of forest fire occurrence. This makes it an extremely difficult task to identify factors consistently influencing forest fire occurrence. Chuvieco and Congalton (1989) suggest that the following basic factors are important influences in fire hazard: vegetation (potential fuel), slope, aspect, elevation, and presence of roads/trails. The main factor affecting fire hazard is obviously the type and characteristics of the vegetation, as this represents the total fuel available for the fire. The impacts of elevation, slope, and aspect in fire hazard have been widely reported in the literature (Brown and Davis, 1973: Artsybashev, 1983). Slope is considered a major factor, increasing the rate of spread because of more efficient convective preheating and ignition by point contact. Minninch (1978) suggests that slopes containing water courses or cliffs suppress the movement of the fire. Aspect is considered to influence fire hazard, which is an important factor in the rate of fuel drying. In mountain environments, increased elevation is related to higher precipitation, and therefore a possible factor contributing to the suppression of fire occurrence.

The presence of roads and trails throughout the area can be considered as a factor influencing both the suppression and the cause of fire. Firstly, they act as breaks in the vegetation, thus reducing the potential of fire and its spread. Alternatively, they represent more intense human activity, thus increasing the potential for fire ignition. Forest fire occurrence is reportedly more frequent during the dry summer months (Hawkes, 1979), although incidents may occur throughout most of the year.

Rockslides and rockfalls can be damaging and disrupting to a variety of human activities and land uses in mountainous areas (Gardner *et al.*, 1983). Much research has been carried out in order to understand the processes involved in such events, and there is still considerable debate relating to the type of motion involved in high velocity/high magnitude rockslides/rockfalls subsequent to initial failure (Hsu, 1975). The distinction between rockslide and rockfall is related to the characteristics of initial motion (Bjerrum and Jørstad, 1968). Rockfall usually implies some free-falling motion often accompanied by bouncing and rolling of individual particles, whereas rockslides can be translated into free fall and bouncing and rolling, depending on the morphology of the surface over which the rock mass is moving. Gardner *et al.* (1983) notes that different terms, such as landslide and "bergsturz", are applied to rockfalls and rockslides of greatly different characteristics.

Associations between distribution of environmental factors such as elevation, slope, aspect, and geology, and rockslide/rockfall occurrence, can lead to inferences about cause. Gardner *et al.* (1983) suggests that, because scarp slopes are generally steeper than dip slopes, and both were subject to the same glacial influences in the late pleistocene, steepness of the slope is a primary influence on the location of failures, also note that a high percentage of rockslide/rockfall occurrences is on Rundle group limestones and dolomites, suggesting that the numerous bedding planes and joints lead to extensive physical and chemical weathering. Although the preferred aspect of high rockslide/rockfall occurrences suggests the importance of topographic and geological factors, Gardner (1983) suggests that micro climatic conditions may be important too. Northerly exposures above 2200m usually maintain some snow and ice throughout the year, suggesting the likelihood of more freeze/thaw cycles. This is a possible explanation for more occurrences at higher elevations with a northerly aspect (Gardner *et al.*, 1983).

Floods are among the most damaging of all natural hazards in the Canadian environment (Gardner, 1981). Heavy snowfall, rapid and erratic snowmelt, intense rainstorms, the presence of ice in rivers, and steep slopes, all make mountain areas particularly prone to damaging floods. The causes of flooding are exceedingly complex. Gardner (1981) notes that the creation and changing characteristics of flood hazard in the Bow Valley region of southern Alberta, has been the result of a complex of natural environmental and human factors. Despite the decline of glacier ice and seasonal snow cover storage during the past 50 years, the potential for flooding is still ever present (Gardner, 1981). Areas of land for human occupance are severely limited in mountainous areas, with valley bottoms providing the majority of flat fertile land, which in many cases, are the same areas subject to flooding.

The Little Ice Age has seen some significant climate shifts in the Rockies, including a glacial advance followed by a recession in the past 150 years, which may have been responsible for generating higher than present discharges (Gardner, 1981). However, Gardner (1981) notes that other factors may be involved also, for example, forest fires related to landuse activities. Nelson and Byrne (1966) make reference to the relationships between extensive burning and the production of high magnitude flooding. In general, though, heavy snow and/or copious rainfall may produce damaging floods, especially during the period of spring melt.

CHAPTER 4

Methodology

This chapter discusses the methodological approach utilized, with the following topics addressed: data sources, input, and storage; data analysis, including hazard mapping, prediction, and risk estimation; data output; and data accuracy.

Data for relevant variables in the study area was obtained from a variety of sources, both in digital and analogue format. Due to the disparate sources, a first major task was to bring together and store the information in compatible formats. Once this was done, the use of a geographical information system (GIS) enabled all data to be stored and manipulated in digital format, regardless of scale, structure, or source. The analysis involved mapping known hazardous processes and evaluating under what physical conditions they occur. Assumptions were made regarding the conditions associated with the processes, and areas experiencing these same conditions are assumed to be susceptible to the same type of hazard. Both the spatial and temporal aspects of the hazardous processes were identified, and the risk potential estimated for the study area. Data relating to the spatial and temporal aspects of human activity in the park were combined with the risk potential maps to produce an estimation of the spatial and temporal nature of actual risk. Output consisted of hazard susceptibility maps, in addition to potential and actual risk maps.

Data accuracy and errors involved with the methodology are also discussed, in order to give an indication of how accurate the final results are.

The procedures described are implemented through the use of a GIS, which provides an integrated system for data storage, analysis, and output. Burrough (1986) describes a GIS as a powerful set of tools for collecting, storing, selectively retrieving, transforming, and displaying spatial data from the real world for a particular set of purposes. The GIS used for this research is SPANS version 5.2. SPANS stands for Spatial Analysis System and is a PC based program developed by Intera TYDAC Technologies Ltd., running under the IBM[2] Operating System 2 (OS/2) platform. The hardware consisted of an 80486/33 Mhz[3] machine with VGA[4], 200 megabyte drive, 8 megabytes RAM[5], 80387 math coprocessor, and operating under the OS/2 version 1.2 extended edition with a dual boot to DOS facility. Digital input of data was performed on a 36" X 24" Gentian GTC05 digitizing tablet, and output was obtained via a QMS 800 II postscript printer.

In order to understand better the procedures carried out with the aid of a GIS, an understanding of the methods of data storage and structure is important. All

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[2] International Business Machines

[3] Megahertz, relating to the speed of the computer

[4] Video Graphics Adaptor

[5] Random Access Memory

strictly spatial data can be reduced to three basic topological concepts; the point, the line, and the area (Burrough, 1986). These three features can be defined both by position with reference to a coordinate system, and by their non-spatial attributes. There are two fundamental ways of representing topological data, raster or vector data structure. Raster representation consists of an array of grid cells or pixels, each being referenced by a row and column number and containing a value representing the attribute being mapped. Vector data structures attempt to represent the object as exactly as possible. The coordinate space is assumed to be continuous, not quantized as with the raster space (Burrough, 1986). This allows all positions, lengths, and dimensions to be defined as precisely as possible, and implicit relations are used that allow complex data to be stored in a minimum of space.

SPANS stores and manipulates data using a refined version of the raster data structure known as quadtrees. This is based on successive division of the 2^n X 2^n array into quadrants. A region is tiled by subdividing the array step by step into quadrants and noting which quadrants are wholly contained within the region. The lower limit of division is the single pixel. Quadtrees have many interesting advantages over other methods of raster representation. Standard region properties can be easily and efficiently computed. Quadtrees are 'variable resolution' arrays in which detail is represented only when available without requiring excessive storage for parts where detail is lacking. This research was carried out with a grid resolution of 12 metres. SPANS is also linked to the database management system of OS/2, a relational database using structured query language (SQL), allowing non-spatial attributes to be stored and manipulated effectively.

Although stored as raster, data can be input regardless of its structure, that is, point, line and area data can be utilized. Point data is input as a series of x and y coordinates with related attributes. These points can then be transformed into quadtree (or raster format) by creating buffers around the points and assigning a value to the buffer zone, which can subsequently be used in the analysis with other maps. Line and area data are input as line data structure. In the case of areal data, the linework is converted to polygonal information, which is subsequently transformed into quadtree format. Attributes can then be associated with these polygons for analysis. Linear features can be stored and utilized as such (e.g. for network analysis), or they can also be transformed into quadtree format by creating buffers around the features in the same manner as point data. Figure 4.1 illustrates the conceptual framework of the GIS with reference to the data used.

4.1 Data Sources and Input

A variety of data sources relating to both the physical characteristics and the human activity in the area were collected. These data can be categorized both by their spatial structure (point, line, or area) and also by what they represent (the physical or human component), illustrated in Figure 4.2. In some cases the data

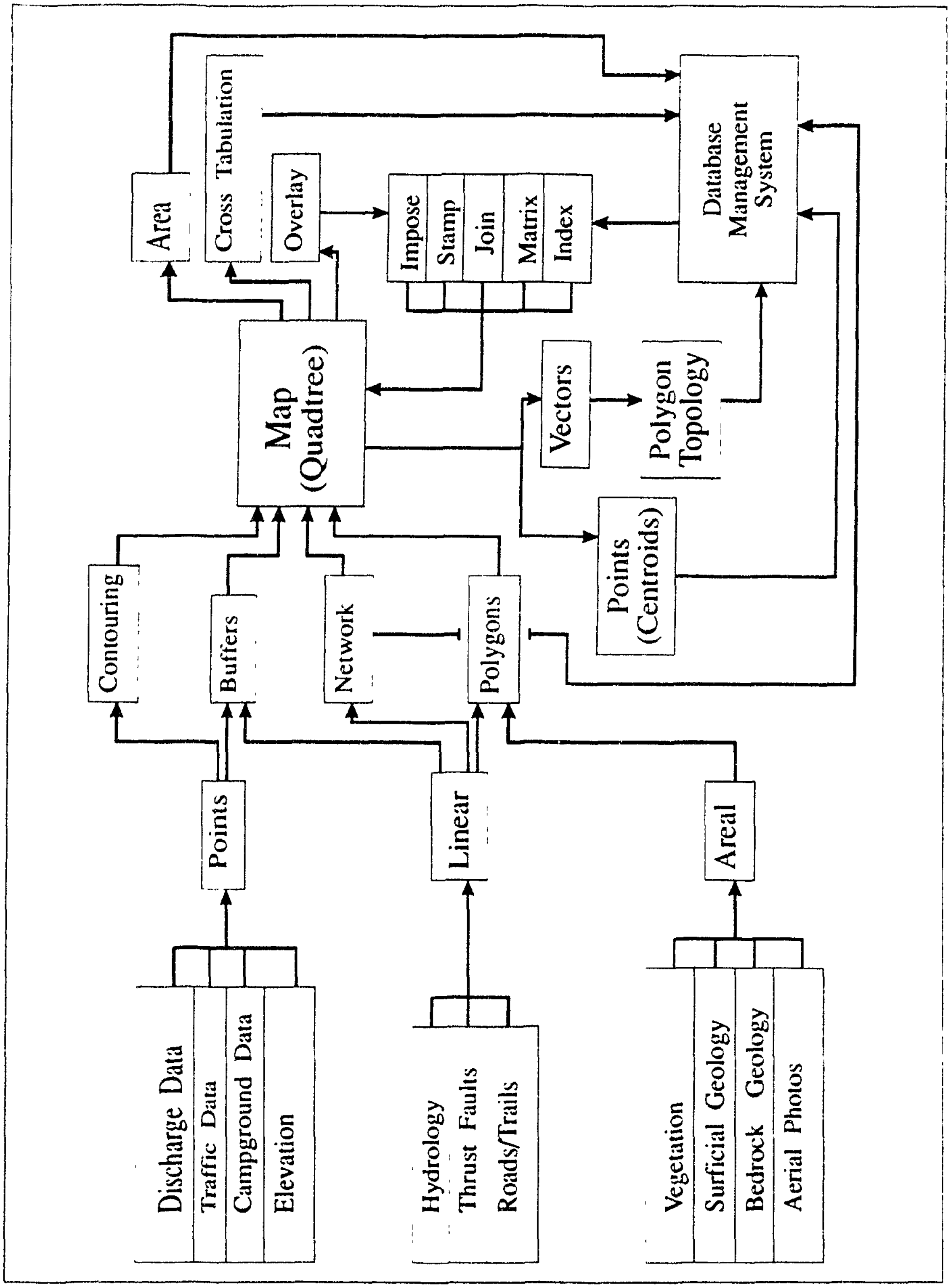


Figure 4.1: Conceptual Framework of SPANS

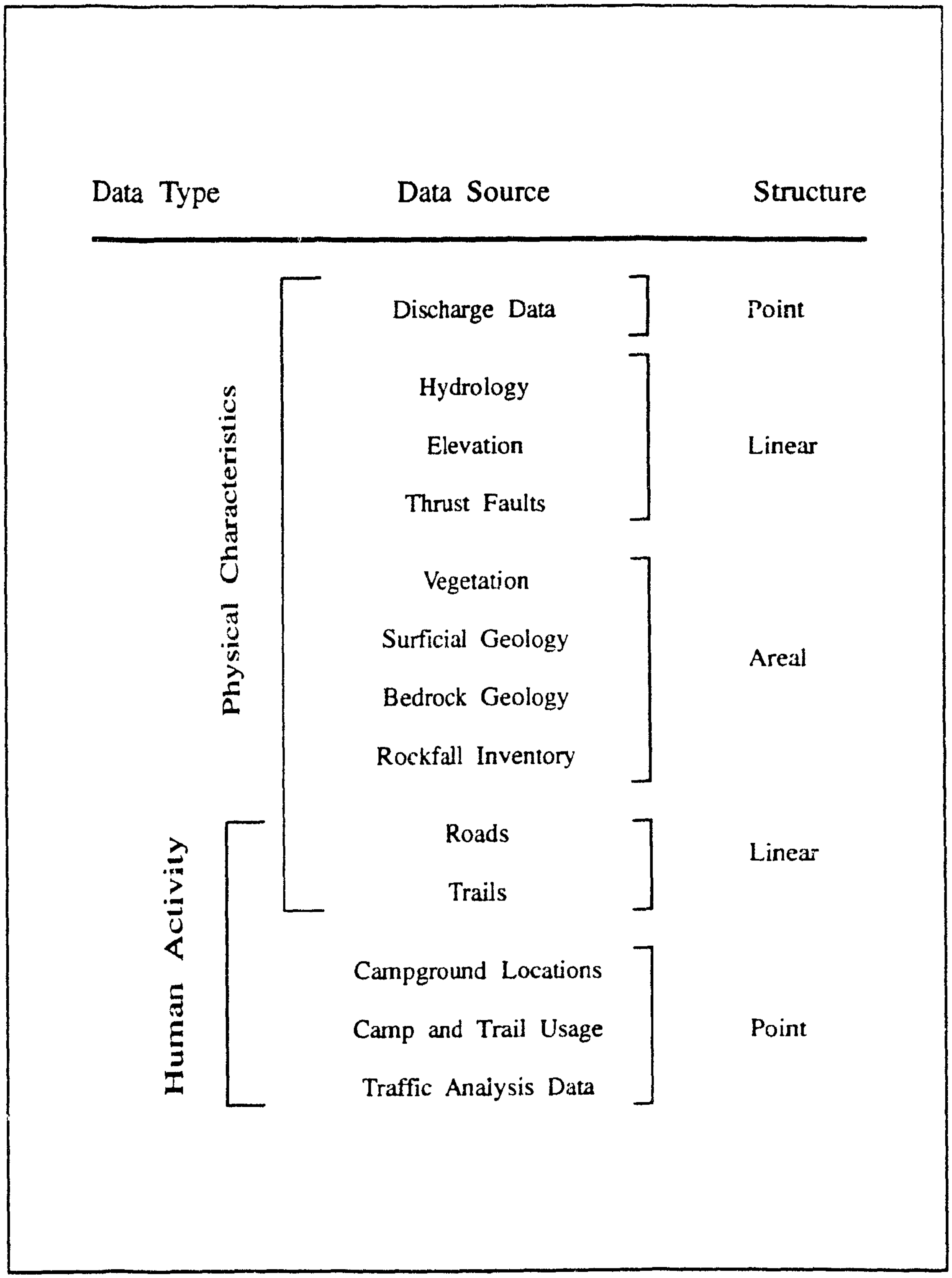


Figure 4.2: Data Sources and Spatial Structure

source has been shown to represent both the physical and human component, for example with roads. This can be explained by the fact that they are not only used to represent human artifacts in the area, but also a "physical" break in the landscape, relevant in the case of assessing fire hazard for example. The various data sources and their input into the GIS are described in more detail:

4.1.1 Topographic Data

Main rivers, streams, contour lines, roads, and trails, were obtained from the National Topographic map sheets 82J10, 82J11 and 82J14 at the 1:50 000 scale. Hydrography, roads and trails were input by digitizing the features desired. Contour lines were digitized at the 500 foot interval in order to provide sufficient detail of the area. The digitized contours were converted into a series of x, y, z spot heights and interpolated using the Triangulated Irregular Network[6] (TIN) method. Over 25 000 points were used to represent the study area, giving a point density of approximately 20 m^2. Elevation, slope and aspect data were derived from the TIN and classified into 100m, 5 degree, and 22.5 degree intervals respectively. These intervals were chosen in order to represent the data in sufficient detail, but without making processing times excessive.

[6] A TIN is a terrain model that uses a sheet of continuous, connected triangular facets based on a Delaunay triangulation of irregularly spaced nodes or observation points (Burrough, 1986).

4.1.2 Vegetation Data

Detailed vegetation maps at the 1:50 000 scale were obtained from the 1978 and 1989 surveys (Kondla, N., 1978, 1989), allowing comparisons to be made during the 11 year period. These maps were digitized and classified under the following 45 categories:

Coniferous forest
- Lodgepole Pine forest
  - Open Lodgepole Pine forest
  - Moderately dense Lodgepole Pine forest
  - Dense Lodgepole Pine forest
  - Lodgepole Pine/Sphagnum - Labrador Tea Bog
- Spruce forest
  - Spruce/Feathermoss
  - Spruce/Sphagnum - Labrador Tea Bog
  - Spruce/Willow Alluvium
- Spruce - Pine forest
- Spruce - Alpine fir forest
- Douglas fir forest
- Alpine fir - Spruce - Larch forest
- Alpine fir avalanche track or slope
- Spruce - Pine - fir forest

Deciduous forest
- Aspen Poplar forest
- Balsam Poplar forest

Tall shrub dominated
- Riparian willow
- Wetland willow
- Willow - sedge alluvium

Low shrub dominated
- Birch fen and bog
- Birch - willow fen
- Willow avalanche track or slope
- Buffaloberry - herb slope

Willow fen
Alpine willow
Streamside willow

Herb dominated
Wet sedge fen
Dry sedge fen
Grassland
Dryas drummondii
Herb avalanche track or slope
Horsetail - moss
Dry forb - grass mixture

Lichen/Bryophyte dominated
Lichen dominated
Bryophyte dominated

Miscellaneous mapping types
Burn
Disturbance
Logging complex
Rock outcrop complex
Talus slope complex
Unvegetated

Alpine
Subalpine tree islands with heath - herb clearing
Alpine complex
Alpine meadow heath
Avalanche slope complex
Conifer dominated wetland

4.1.3 Surficial and Bedrock Geology

The 1:50 000 scale surficial geology map compiled in 1976 from the survey by L.E. Jackson was digitized. Classification was broken down into the following categories:

Alluvial Deposits

Alluvial Fan
Floodplain

Colluvial Deposits

Colluvial apron, talus cones and slopes
Rock glacier
Colluvial blanket
Colluvial blanket mixed with glacial till
Colluvial fan; gradational between alluvial fan and talus cone
Colluvial veneer
Glacial ice
Landslide
Organic deposits: bog and fen

Glaciofluvial deposits

Glaciofluvial outwash plain
Glaciofluvial terrace

Morainal deposits

Morainal blanket
Morainal blanket with glaciofluvial materials
Hummocky moraine
Glacial rubble piles
Bouldery ridged morainal deposits
Morainal veneer
Morainal veneer with glaciofluvial deposits

Bedrock

Rolling bedrock topography overlain by glacial till blanket
Rolling bedrock topography overlain by glacial till veneer

Bedrock geology and thrust faults were digitized from the generalized map compiled after McMechlan (1989), Geological Survey of Canada, at a scale of 1:100 000. The following groups were identified:

Cadomin	Kootenay	Banff
Fernie	Spray River	Fairholme
Spray Lakes	Rundle	Palliser
Yahatinda		

4.1.4 Rockslide/Rockfall Inventory Data

Rockslide and rockfall data were digitized from a 1:50 000 map provided by Peter Lougheed Provincial Park. The map was compiled by Mark Pawson in 1986, and identifies rockslide and rockfall zones within the study area.

4.1.5 Hydrological Data

Discharge data were obtained for gauging stations 05BF-002/003/022/010/011/004/008 and 005. The stations and duration of record are shown in Figure 4.3 and locations shown in Figure 1.4. The data were retrieved from the Canada-Surface Water Hydrodata CD ROM Optical Disk in digital format, with daily and peak values covering the entire period of record for each station. The data are derived from the Environment Canada Water Resources Branch HYDAT files that contain surface water data for the provinces and territories of Canada. Average monthly values for the gauging stations were entered into a point table containing the station identifiers and geographic location. Table 4.1 illustrates the structure of these point tables, which contain three distinct components: the header, the data format codes, and the data itself. These tables are created with a text editor and then imported into SPANS. Average monthly values were also stored in spreadsheet format, for the production of graphs relating to each gauging station.

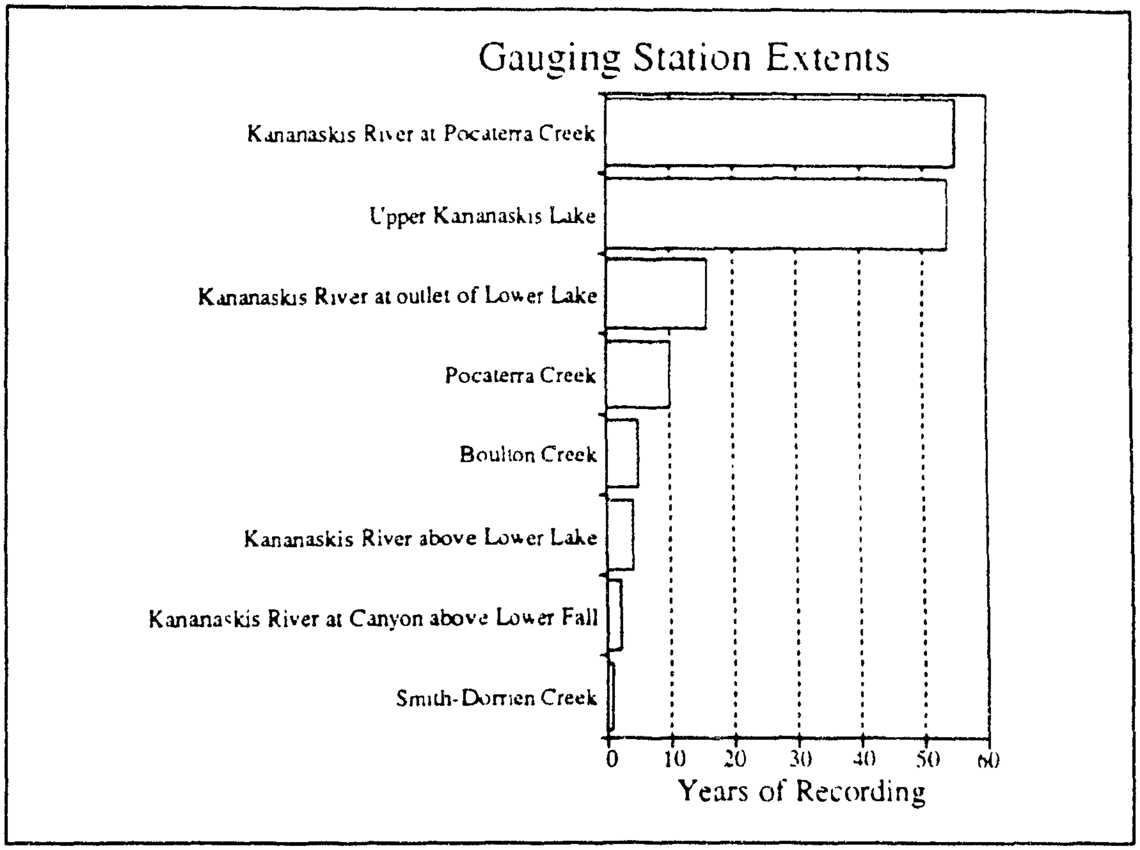


Figure 4.3: Gauging Stations Duration of Record

4.1.6 Human Activity Data

There are no permanent settlements within the study area, however, the presence of people is identified from locations of campgrounds and public facilities in conjunction with backcountry trails and roads. This gives an indication of areas experiencing the most intense human activity. Campground, facility, trail, and road usage data are then combined with locational data to give an indication of the temporal and spatial patterns of human activity in the park. This provides a

ID Discharge
TITLE Discharge Data
MAPID Hydro
WINDOW 00
TABTYPE 2
FTYPE free
KEYFIELD 0

1	5	15.0	0	morton	Morton Number
2	1	3.50	0	lat	Latitude
3	1	3.50	0	lon	Longitude
4	30	30.0	0	id	Gauging Station Identifier
5	1	9.30	0	Jan	Average Daily Discharge - January
6	1	9.30	0	Feb	Average Daily Discharge - February
7	1	9.30	0	Mar	Average Daily Discharge - March
8	1	9.30	0	Apr	Average Daily Discharge - April
9	1	9.30	0	May	Average Daily Discharge - May
10	1	9.30	0	Jun	Average Daily Discharge - June
11	1	9.30	0	Jul	Average Daily Discharge - July
12	1	9.30	0	Aug	Average Daily Discharge - August
13	1	9.30	0	Sep	Average Daily Discharge - September
14	1	9.30	0	Oct	Average Daily Discharge - October
15	1	9.30	0	Nov	Average Daily Discharge - November
16	1	9.30	0	Dec	Average Daily Discharge - December

DATA

3f4f293	05BF005	1691 186	1689 024	1688 371	1688 002	1687 509	1689 479	1693 965	1697 026	1697 994	1698 536	1697 630	1694 423
3f9c3c2	05BF008	0 00	0 00	0 00	0 00	4 932	14 950	8 361	4 680	2 541	1 307	0 00	0 00
609a4c6	05BF004	0 125	0 091	0 084	0 478	1 768	2 842	1 400	0 615	0 411	0 299	0 215	0 154
60a8le3	05BF003	9 365	9 144	7 191	3 857	4 819	10 691	9 732	7 453	5 771	4 294	8 207	9 767
633f4bc	05BF010	5 359	5 394	3 036	1 764	3 041	6 414	8 268	6 587	4 038	2 298	4 146	6 180
9565dbf	05BF002	2 759	1 846	0 786	0 376	4 170	12 596	12 954	10 398	7 131	1.714	1 330	2 705
c0126aa	05BF022	4 679	5 314	1 645	3 376	8 782	18 388	17 919	15 235	11 658	2 936	2 439	5 412
c024e99	05BF011	0 00	0 00	0 00	0 00	1 015	1 157	0 589	0 196	0 119	0 099	0 057	0 00

Table 4.1: Hydrological Data Table Structure

representation of the human component needed in the risk assessment process.

Traffic analysis data for the period 1984-1989, consisting of average monthly values, was obtained for counters 040121T and 040106T. These are located 5km south of intersection of Highways 1 and 40 at Barrier Lake and 9km north of intersection of Highway 40 and Kananaskis Trail respectively. The data is derived from daily readings of vehicles for the period mentioned. These data were stored in point tables, consisting of identifier and geographic location, and imported into SPANS. In addition, the data was stored in spreadsheet format for the production of graphs.

Campground and trail usage data were obtained, covering the six year period from 1985-1991. The data was broken down into the following categories: campgrounds (auto access), group campgrounds, backcountry campgrounds, William Watson lodge, and facility-day use. Although the data were not broken down by individual campsites or trails, they still provide valuable information regarding human activity within the park. Monthly values indicating total number of persons using each facility enabled figures to be obtained, indicating total overnight accommodation, trail usage and day facility usage. The data were stored in spreadsheet format to allow for production and analysis of graphs. Campsite locations were digitized from a visitor map of the park, produced by Alberta Parks and Recreation.

4.2 Data Analysis

4.2.1 Hazard Mapping and Prediction

The initial stages of hazard prediction involves mapping known hazards. This gives an insight as to their spatial distribution and under what environmental conditions these generative physical processes take place. For the purposes of this research, the types of hazard considered are snow avalanche, forest fire, rockslide/rockfall and flood. These hazardous processes are identified from the data sources described previously, and stored as hazard inventory maps representing each individual process.

Avalanches were identified by reclassifying the 1978 and 1989 vegetation maps to show areas that represent Alpine Fir, Alpine, Willow, and Herb avalanche tracks. The reclassified 1978 and 1989 vegetation maps were then combined by means of a simple overlay, to produce a hazard map of known avalanche occurrence. Forest Fire hazard maps were produced in the same manner, by reclassifying both the vegetation maps to illustrate burned areas and then combining the two maps. Rockslide/rockfall occurrence were identified from the rockslide inventory map, and flood hazard from the surficial geology map, by reclassifying the map to illustrate alluvial floodplains and glaciofluvial outwash plains.

Prediction of hazardous events, involving the processes described, entails making assumptions about the characteristics associated with those events. That is, for any particular hazardous event, it is assumed that areas experiencing the same physical conditions will be susceptible to the same type of hazard. For example, in the case of avalanche hazard, the identified tracks are analyzed in terms of topographic conditions they are associated with, such as slope, aspect, and elevation. This provides an indication of which conditions appear more conducive to occurrence of that particular hazard. This is performed for each hazardous process, and provides a simple yet effective procedure that is efficiently carried out using a geographical information system.

Each individual hazard inventory map is analyzed with respect to a variety of other data, such as elevation, aspect, slope, geology, vegetation, hydrology, and thrust faults, depending on which hazard is being examined. This is achieved by means of an area cross tabulation, whereby two data sets are overlayed to find the common occurrences. For example, the avalanche hazard inventory map was cross tabulated with elevation to indicate the frequency of occurrence of avalanches within each elevation band. Table 4.2 illustrates the results from performing an area cross tabulation between avalanche hazard and elevation. The header of the cross tabulation matrix (correlation report) indicates which data sets are used in the analysis, in addition to chi square coefficients.

AREA CROSS TABULATION

Row	elev100	:	Elevation (100m Bands)
Col	avalanch	:	Avalanche Slopes (4 Classes)
Win	00		Universe

Contingency Coefficient	0.3747
Tschuprow's T	0 1471
Cramer's V	0.2333

Area (km²)
Total %
Row %
Col %

	alpfir	willow	herb	alpine	Total
16-17	0 0000 0 00 0 00 0 00	0 0101 0 07 8 05 0 40	0 0193 0 14 15 45 1 65	0 0958 0 70 76 51 3 66	0 1252 0 92
17 18	0 0257 0 19 4 99 0 35	0 1777 1 30 34 56 7 03	0 0424 0.31 8 24 3 63	0 2685 1 96 52.20 10 25	0 5143 3 76
18-19	1 0930 7 99 59 33 14 86	0 3987 2 92 21 64 15 76	0 0582 0 43 3 16 4 98	0 2923 2 14 15 87 11 16	1 8421 13 47
19-20	2 1037 15 39 61 01 28 59	0 6938 5 07 20 12 27 43	0 1177 0 86 7 99 10 07	0 5328 3 90 13 44 20 35	3 4480 25 22
20-21	1 4719 10 76 64 10 20 01	0 3323 2 43 14 47 13 14	0 1836 1 34 7 99 15 70	0 3085 2 26 13 44 11 78	2 2963 16 79
21 22	1 6456 12.03 46 40 22.37	0 7572 5 54 21 35 29 94	0 3177 2.32 8 96 27 18	0 8258 6 04 23 29 31 54	3 5463 25 94
22 23	0 8538 6 24 55 47 11 60	0 1309 0 96 8 50 5 18	0 2700 1 97 17 54 23 10	0 2846 2 08 18 49 10 87	1 5392 11 26
23 24	0 1437 1 05 47 49 1 95	0 0284 0 21 9 38 1 12	0 1202 0 88 39 73 10 29	0 0103 0 08 3 39 0 39	0 3026 2 21
24-25	0 0199 0 15 33 39 0 27	0 0000 0 00 0 00 0 00	0 0398 0 29 66 61 3 40	0 0000 0 00 0 00 0 00	0 0597 0 44
Total	7 3572 53 81	2 5291 18 50	1 1689 8 55	2 6185 19 15	13 6737

Table 4.2: Area Cross Tabulation Matrix

The results are presented both in area (km^2) and in percentage of the total area, which are then imported into a spreadsheet for production of graphs. These graphs are analyzed to illustrate any correlation between the hazardous process and the various data sets. Table 4.3 illustrates which data sets are used for cross tabulation analysis with each hazard. Analysis of the graphs, in conjunction with the cross tabulation coefficients and referral to previous research of this nature, leads to an understanding of the spatial distribution of the hazardous processes. This allows the data sets used in the cross tabulation with each hazard, to be ranked according to their perceived importance as contributing factors to that process. This involves examining the correlation coefficients from the cross tabulation results, the results from the graphs produced, and using our knowledge of that process, to determine which factor or factors are most related to that process. A low correlation coefficient between slope angle and avalanche occurrence, for example, suggests that only certain slope angles play an important role in avalanche hazard. The frequency graphs produced are then analyzed to show which categories in that data set appear to be related to the hazardous process. High frequencies of occurrence within particular range of values, for slope for example, suggest that range of slope angles to be more conducive to avalanche occurrence. In addition to using the quantitative results from the analysis, previous knowledge of factors influencing the hazardous process are introduced in order to compensate for any erratic results obtained from the cross tabulation process.

Data Set	Hazardous Process			
	Avalanche	Forest Fire	Rockslide/fall	Flood
Elevation	X	X	X	X
Slope	X	X	X	X
Aspect	X	X	X	X
Vegetation	X	X		
Surficial Geology				X
Bedrock Geology			X	
Proximity to Rivers		X		X
Proximity to Thrust Faults			X	
Proximity to Roads/Trails		X		

Table 4.3: Data Sets used for Cross Tabulation Analysis

This is reflected by giving each data set a 'weight' representing its determined importance. With the case of avalanche hazard, for example, elevation, slope, aspect, and vegetation data were used in the cross tabulation analysis, and each of these data sets weighted according to their determined importance. This involves giving each data set a percentage value, which assumes that these are the only factors involved in avalanche occurrence. In addition to each data set receiving a weight, the classes within each data set are given a ranking based on a low/medium/high scale, with 1 representing low probability, and 3 representing high probability. These ranks are assigned by analyzing the graphs produced by the cross tabulation results, with classes having a high frequency of hazard occurrence, being assigned a high probability level. Classes within the data set containing no, or low occurrences are assigned a low probability level.

Thus, for each hazardous process, the factors believed to be important in its occurrence are identified from knowledge of that process. These factors or data sets are cross tabulated with the inventory maps of each hazard to determine any correlation between the two. Weights are assigned to each data set representing its determined importance as an influential factor in occurrence, and probability rankings are assigned to the classes within each data set to represent which range of values are more conducive to the hazard occurrence. The weights and ranks determined for each hazard are then combined in the form of an 'index overlay', in order to produce hazard susceptibility maps. Figure 5.5 illustrates the index overlay template used to create the avalanche susceptibility map. Each data set is represented by a weight or percentage, and each class within the data sets is assigned a probability ranking or index.

The weights specify the importance of each data set input for analysis, and the probability rankings represent an assessment of relative importance of the classes within each data set. The susceptibility maps created by the index overlays are calculated as follows:

$$Score = \frac{Rank \times Weight}{\sum Weights}$$

The resultant maps define areas as susceptible to that particular hazard on the basis of the assumptions. The maps illustrate high, medium, and low potential areas for avalanche, forest fire, rockslide/rockfall, and flood hazard occurrence. These susceptibility maps were created using only the physical characteristics associated with the hazards, and the data available. It is recognized that the conditions responsible for triggering damaging events associated with hazards, are far more complicated than this analysis suggests, but limited data sources preclude a more detailed analysis. It is the methodological procedures that are of primary interest, to provide a basic model for hazard assessment in such a mountain environment. Figure 4.4 represents the procedures used in the hazard mapping and prediction process.

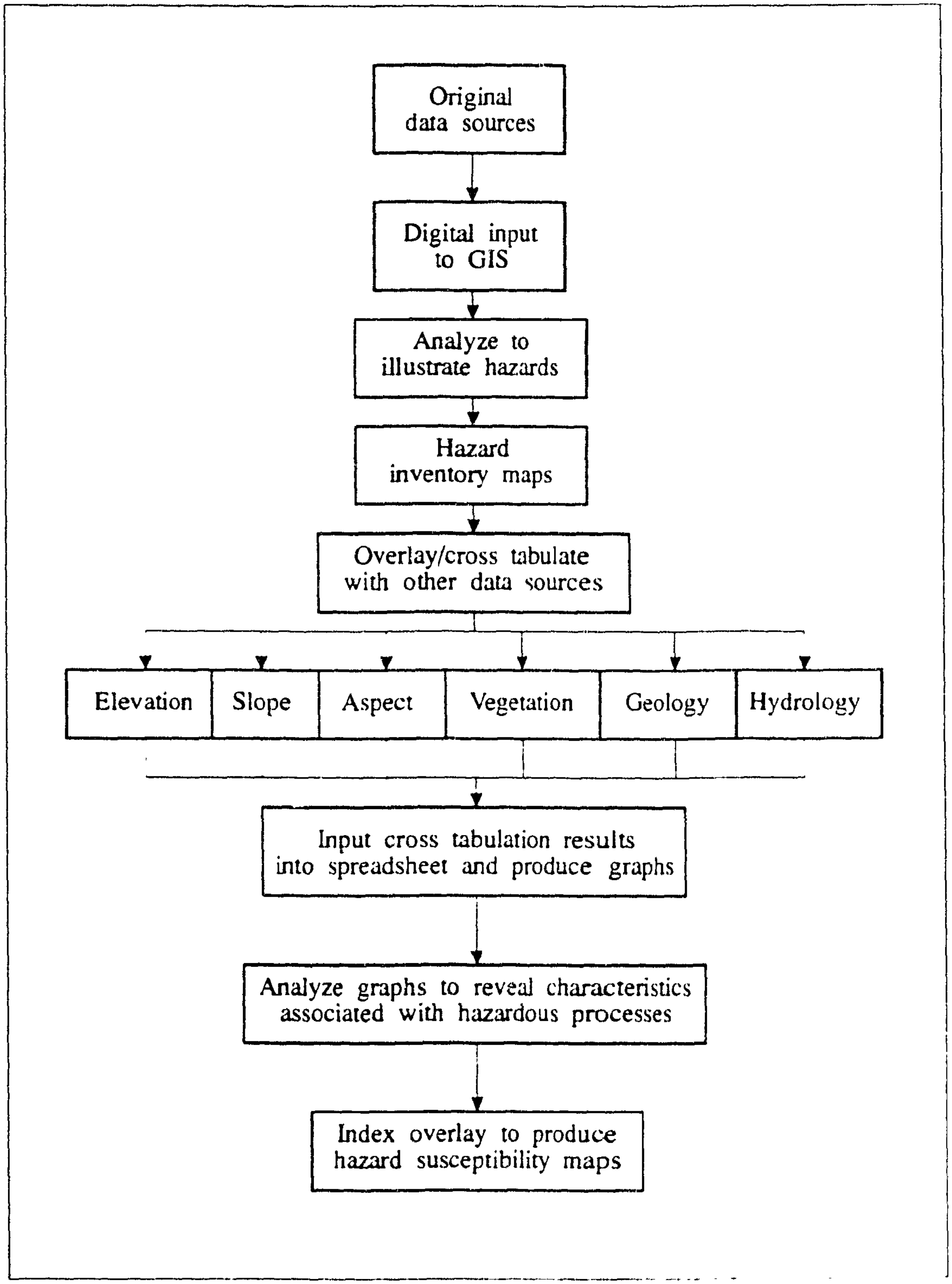


Figure 4.4: Hazard Mapping and Prediction Procedures

4.2.2 Risk Estimation

Risk estimation seeks to scientifically determine the nature and level of the risk involved, usually from an analysis of known occurrences over time and space (Whyte and Burton, 1980). Risk can be taken to mean a hazard or danger with adverse probabilistic consequences for society and environment, and can be defined as probability times consequence. Whyte (1983) states that risk estimation relies heavily on qualitative information, which is not necessarily weak, but does incur some limitations. This research attempts to quantify, as accurately as possible, the risk estimation process.

For the purpose of this research, the risk estimation process is carried out in two stages. First of all, the risk potential is calculated for the area, with respect to all the hazards identified. Risk potential can be considered as the total risk at any one place from all the hazardous processes. It takes into account the spatial and temporal nature of the physical processes occurring in the study area, and attempts to quantify the results. The second stage of the process is to calculate the actual risk, which involves combining the risk potential with human activity in the area. This takes into account the temporal and spatial nature of both the hazardous processes and the human activity.

Risk potential is calculated by overlaying the hazard susceptibility maps produced. This is a standard procedure in hazard research and serves to illustrate hazardous areas or potentially hazardous areas, but it fails to take into account the temporal nature of the processes. This research attempts to overcome this limitation by using index overlays, where each hazard susceptibility map is assigned a weight representing its relative importance on a temporal scale. That is, for each month, an index overlay is performed to reflect the probability of each hazard occurring at that time of year. The index overlay provides a method of overlaying data layers or maps while taking into account the relative importance of each layer. The criteria for the weights assigned are derived from analysis of frequency data relating to each hazard, giving an indication of likelihood of occurrence at any time of year. The temporal nature of each hazard was determined either by analyzing frequency data related to the process, or by relying on previous research related to the hazard in conjunction with knowledge of the process. The temporal nature of floods were determined by analyzing the average monthly flows of the gauging stations in the park, indicating which months are more susceptible to flooding. Lack of frequency data relating to avalanche, forest fire, and rockslide/rockfall occurrence, meant relying on previous research results in the area to determine temporal patterns. Thus, risk potential maps can be created to represent different times of year, providing the temporal and spatial relationships of hazardous processes in the area.

Actual risk maps are created by utilizing the potential risk maps created, and integrating these with human activity within the park. Data relating to campsite, road and trail locations and usage were analyzed to provide the human component, and subsequently overlayed with the absolute risk maps representing the physical processes. These maps indicate the risk from hazards relative to human activity, taking into account the highly temporal and spatial nature of both. Human activity is represented by creating buffers around the point (campsites) or linear features (roads and trails). Activity is considered to be more intense in close proximity to these features, thus radial and corridor buffers are created around point and linear data respectively, to represent decreasing activity as distance from the features increases. Arbitrary values are assigned to these buffers, with areas immediately surrounding the features are assigned a value of 3, representing high activity, and areas beyond a critical distance assigned a value of 0, representing no activity. The sizes of these buffers attempt to reflect the activity around the features, and can be modified to take into account the highly temporal nature of this activity. For example, certain campsites are closed during the winter and therefore have little, or more likely, no activity. The distances used for the buffers, selected to represent the different levels of activity around the feature, were based upon value judgements and thus of primary concern to the final results. Buffer intervals of 50m, 100m, 500m and greater than 500m were used, with high, medium, low, and no activity classes assigned respectively.

These maps representing the human component (with areas of high, medium, and low activity) are then overlayed with the risk potential maps to illustrate areas where potential disasters may occur. The maps contain nine categories, representing areas of low potential for hazards and low activity through to high potential for hazards and high activity, with the latter areas being of primary concern. In both stages of the risk estimation process, the ability to change the criteria used to create the maps is there, providing a flexible approach to take into account new or changing factors. The weights assigned in the index overlay procedure can be altered at any time to reflect changing conditions, such as excessive precipitation, which may lead to increased flooding.

4.3 Data Output

A major concern in hazard research is the presentation of information in an accurate and interpretable format. Large amounts of data are generated in multiple hazard research, and this creates the problem of efficient cartographic representation. The majority of research to date on multiple hazards has employed specialized geomorphic maps combined with snow avalanche maps (Kienholz, 1978; Ives and Bovis, 1978, Hestnes and Lied, 1978). In general, though, most specialized geomorphic maps are beyond the comprehension of non-geomorphologists (Salome *et al.*, 1982). Clearly there are two issues that need to be addressed, the purpose of the research, and who will be the user of such information. Typically, hazard research is conducted with the land use planner in mind. If this is the case, the presentation of results should be targeted for the non-specialist user, and therefore simplicity of the map is of utmost importance. A balance must be struck between displaying the maximum amount of information possible and ease of interpretation.

This research is ultimately concerned with providing results that are of use to the land use planner, and thus attempts to provide a suitable method for presenting the information for this purpose. The use of a geographical information system provides a flexible technique for output of results, allowing data to be selectively retrieved depending on what purpose it is required. For example, information relating to all or individual hazards can be obtained, and combined in any conceivable way. Output can be in the form of a hard copy, from the computer screen, or in the form of digital files. The susceptibility maps produced contain only three classes; high, medium, and low susceptibility. Other features, such as roads, trails, or contours, were omitted to clarify the map and concentrate on the susceptibility ratings. If the maps were to be directed to a larger output device, then significantly more detail could be incorporated into the final map.

Hazard susceptibility and risk maps are obtained in hard copy format for incorporation into the text, but there are some limitations associated with these maps, which must be addressed. The geographical information system used for the analysis is a raster based system, of which the output is generally of poorer quality than vector output. Hardcopy output can be obtained by sending screen dumps to a Paintjet printer or by vectorizing the images and plotting or importing into third party software. The latter option is used for presentation of results, with vector images imported to AutoCad for illustration and final output via postscript printer. Due to the small page size required, the results are generalized by running a smoothing algorithm before vectorizing, for ease of interpretation, and thus a loss in accuracy is experienced. Also, these vectorized files tend to be extremely large in size, and the procedure for obtaining final output is tedious.

More informative output can be achieved via the user interface of the geographical information system. This allow the user interactive access to information relating to the study area and the hazards analyzed. The interface runs under the graphical OS/2 environment which is mouse driven and has an on-line help facility. This provides a sophisticated method for data analysis and retrieval, that can be utilized by the non-specialized user for a variety of purposes. More detailed classifications can be utilized to give a more accurate representation of the susceptibility maps. For example, with a 256 color monitor, a maximum of 256 classes could be used to represent hazard susceptibility instead of the high/medium/low classes used in this analysis. In addition, other data is easily added or removed from the maps, for example, road networks, campsite locations or trails. This provides the user with total control of the image, allowing all data sets to be combined in any way conceivable.

4.4 Data Accuracy

Data accuracy is a key issue in any type of research and especially important in hazard and risk assessment. It is implicit in the whole business of geographical resource information processing that the collection and processing of environmental data leads to improvements in environmental management (Burrough, 1986). This can only be so if the data that are collected, entered, stored and processed are sufficiently reliable and error-free for the purposes for which they are required.

Errors arise from the original sources, the digital input of maps into the database, the processing of data within the computer, and output of final results. The most obvious sources of error are from the original data (for example, age of data, scale, density of observations), then the inputting of the data into the database, and finally the computer processing and output errors. The digital map is almost certainly derived from digitizing a paper version, and this leads to two sources of potential errors; errors in the source map and errors associated with digital representation. As well as the problems inherent in the data indicated, there are other sources of unseen error that can originate in the computer. The most easily forgotten yet critical aspect of the computer processing is the ability of the computer to be able to store and process data at the required level of precision (Burrough, 1986). Insufficient precision in data representation can lead to serious errors in calculations. Many kinds of error can be detected before data are input to the system, or can be caught during data entry. In the case of processing errors, these are more subtle and therefore potentially damaging, often escaping the users of geographical information systems. There are many possible sources of error involved with the methodology employed. These sources are identified and a systematic discussion of the errors involved from the data sources themselves, through to the output of results, is presented.

The first source of error arises from the original data sources, which is difficult to quantify without in depth knowledge of how the data was collected. All the data used was secondary data, and detailed explanations of capture methods were not available. A large majority of the data was maps at various scales, produced from surveys of the park, with the remaining obtained in tabular format. Data input represents the next source of error, with digitizing being the primary method. Digitizing was carried out at 0.3mm tolerance, representing an error margin of 15 metres on a 1:50 000, or 30 metres on a 1:100 000 scale map. Data input was carried out in a manner to reduce errors to a minimum, involving careful digitizing and error checking. Tabular data was input into spreadsheets and point tables with careful error checking for each data set.

Data representation or storage is the next potential source of error, with vector data being converted into raster data structure. Each grid cell or pixel can only contain one value, thus, if the accuracy of the original map exceeds the resolution of the raster grid, data representation is lost in the conversion. The data was stored in

SPANS quadtree format at a resolution of 12 metres, which exceeds the accuracy of the digitizer tolerance by 3 metres on a 1:50 000 map, and 18 metres on a 1:100 000 map. The methods by which elevation, slope, and aspect are represented involve generalization errors. These data sets are classified into user defined intervals in order to reduce processing times and aid in ease of interpreting results. In addition, these data were obtained by interpolation of point data, which involves calculating averages for areas where no data exists. Many errors are associated with the data analysis and classification procedures. These arise from topological map overlay and through applying particular algorithms to variable data that are assumed to be 'uniform' (Burrough, 1986). This is especially true of the index overlays, where a number of data sets with generalized classifications are overlayed to produce a composite map. The algorithm used to overlay the maps involves generalization of the original classes by rounding to the nearest integer, and thus is prone to error. The weights and probability rankings assigned to the maps, represent the fundamental source of error. These values are based on imprecise assumptions made with respect to the hazardous processes, and thus are of primary concern to the research. Errors are also associated with hard copy output of the results, which involves running a smoothing algorithm on the raster image, and then vectorizing the raster image for exporting to third party software. Again, this procedure involves generalization of the data, leading to final results that represent a long chain of generalizations.

CHAPTER 5

Modelling Results

This chapter deals with the analysis and results from the hazard prediction and risk estimation procedures. Individual hazards are analyzed with respect to the data collected, and the results used to aid in the prediction process. Susceptibility maps for each hazardous process are presented with an explanation of the procedures and criteria involved in their production. In conjunction with the physical processes investigated, human activity in the study area is analyzed. These two components are integrated to provide an assessment of the actual risk, taking into consideration the highly spatial and temporal nature of both.

5.1 Hazard Prediction

The results from analysis of the spatial distribution of individual hazards are examined in an attempt to determine any conditions associated with the processes occurring. These are used as criteria in the prediction process, in conjunction with conclusions from previous research investigating such hazards. For present purposes, the assumption is made that these criteria reflect the nature and occurrence of the processes, and that areas experiencing these same conditions have a high probability of experiencing the hazardous process. However, these should not be interpreted as actual susceptibility maps of the area.

5.1.1 Avalanches

Avalanche tracks were cross tabulated with elevation, slope, and aspect data, with the results illustrated in Figures 5.1 through 5.3 respectively. The elevational distribution of the avalanche tracks reveals that over 95% occur in the 1800m to 2300m elevation band. This corresponds to both the upper limit of vegetation, with unvegetated areas becoming increasingly abundant above 2200m, and increasing slope angles at higher elevations. The distribution of avalanche tracks with respect to slope angle reveals that over 65% occur on slopes between 15 and 30 degrees. This distribution can be related to method of avalanche identification. That is, tracks and runout zones were identified from disturbances in vegetation. This method, therefore, does not identify the starting zones which generally occur at higher elevations and on steeper slope gradients. Figure 5.4 illustrates avalanche slope morphology, with the starting zones having steeper gradient than the tracks or runout zones. It is recognized, however, that excessively steep slopes do not permit the accumulation of large quantities of snow and therefore experience lower magnitude, but more frequent, avalanches. The distribution of avalanche tracks with respect to aspect shows that over 60% have a north through east orientation. This is a direct result of higher snow accumulation on such slopes, known as lee slope deposition.

Slope is considered to be the most important factor in avalanche occurrence. Slope angles between 0° and 5° were assigned an index of 1 (low), between 5° and 20° an index of 2 (medium), indicating their probability as runout zones, and between 20° and 60° as 3 (high), indicating slopes most conducive to high magnitude avalanches. Slope with gradients between 60° and 75° were assigned an index of 2, reflecting their probability of small, but frequent avalanche occurrence. Slopes above 75° were assigned an index of 1, because of their inability to accumulate large quantities of snow. Aspect is considered the next most important factor, with north easterly orientations indexed at 3, northerly and easterly at an index of 2, and other orientations an index of 1. Elevation is believed to play a lesser, though significant, role in avalanche occurrence as mentioned, with bands between 1500m and 1800m assigned an index of 1, 1800m to 2000m and index of 2, and above 2200m an index of 3. This reflects the higher precipitation and increased snow cover at higher elevations, and also the higher probability of avalanche above the climatic treeline. Vegetation was also considered in the prediction process, with unvegetated areas were indexed at 3, grass dominated and open forest areas at 2, and dense forest at 1. This recognizes the relative importance of vegetation in snow stability and instability. Generally forested areas are not conducive to avalanche, although it is possible, especially during winter thaw and spring melt periods on south facing slopes.

These data were then combined in the form of an index overlay to define areas that meet the suggested criteria for avalanche occurrence. A weight was assigned to each data set relating to its importance as a contributing factor to avalanching, and despite being based on value judgements, attempt to reflect this as accurately as possible. The data sets were weighted as follows:

Slope	50%
Aspect	30%
Elevation	15%
Vegetation	5%

Slope receives the highest weight, based on the fact that without slope angles conducive to avalanche occurrence, the chances of the process occurring are minimal. That is, even if areas meet the other criteria of aspect, elevation, and vegetation, if they do not have steep slopes then the probability of avalanche occurrence is minimal or even nil. It also recognizes the fact, that even if areas experiencing steep slopes do not meet the other conditions, these areas will still be represented with a probability rating in the final map. This logic is applied to all the data sets in order to determine their weights. The index overlay template is illustrated in Figure 5.5, with the resultant map indicating areas of low, medium, high or no probability of avalanche, shown in Figure 5.6. High probability areas occupy a relatively small proportion of the study area (15% or $73km^2$). Over two thirds (69% or $343km^2$) of the area is regarded as having a medium susceptibility to avalanche occurrence, and the remaining 16% ($77km^2$) a low susceptibility factor.

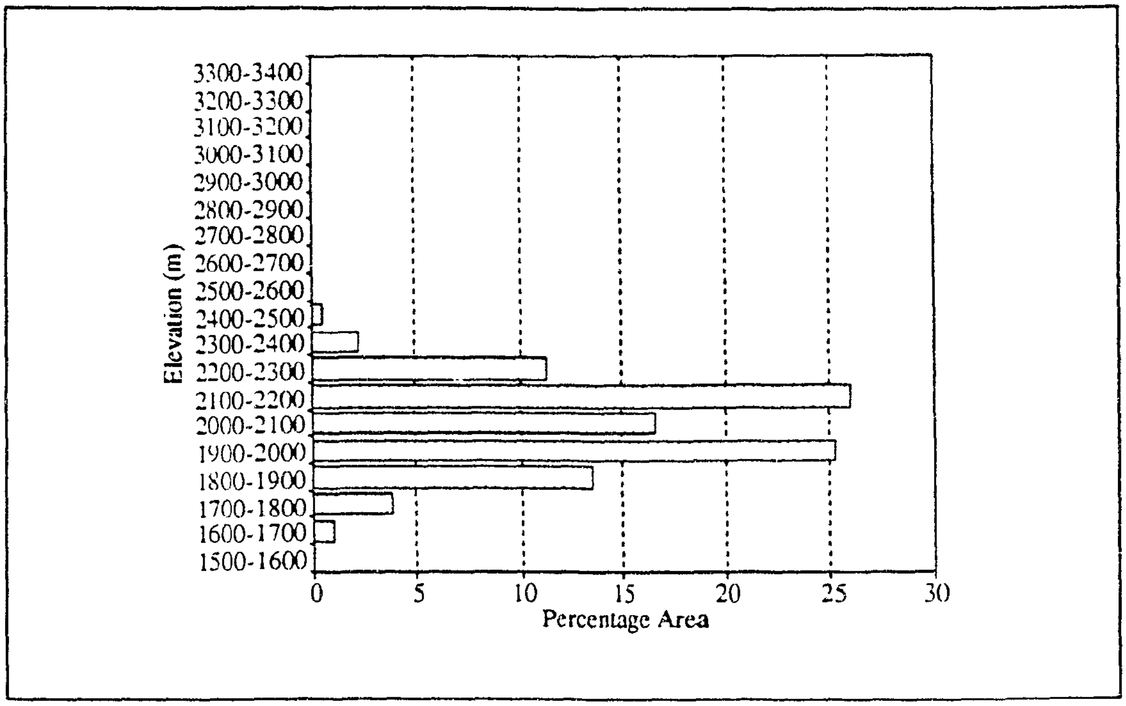


Figure 5.1: Elevational Distribution of Avalanche Tracks

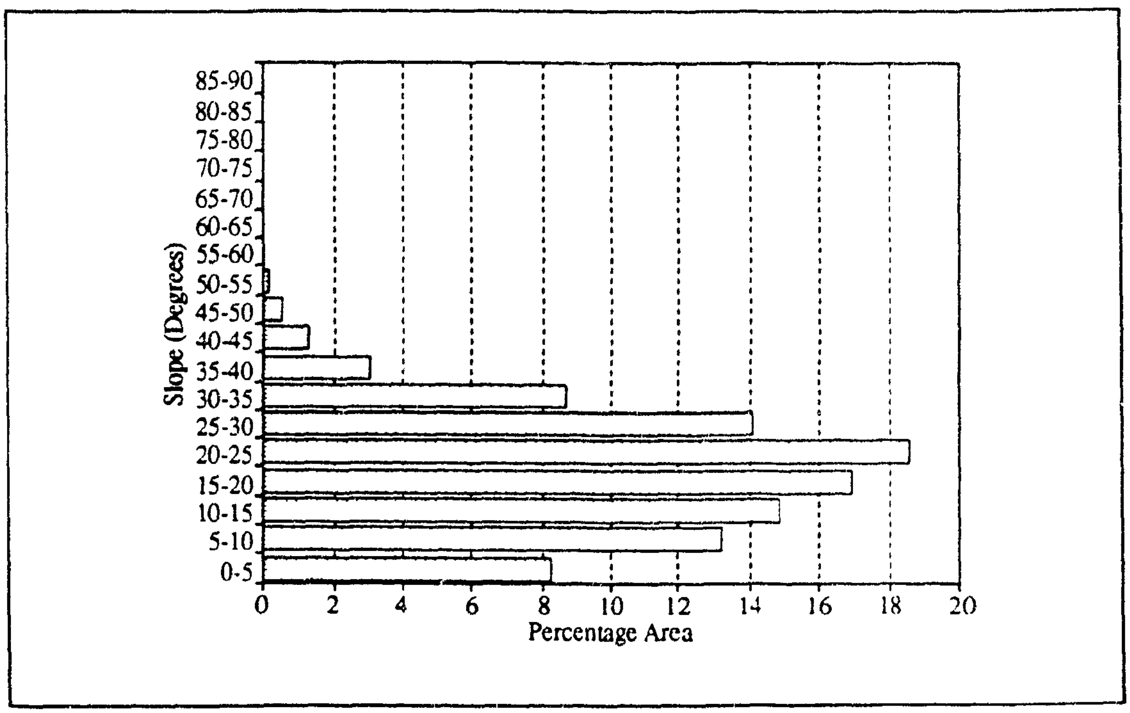


Figure 5.2: Slope Distribution of Avalanche Tracks

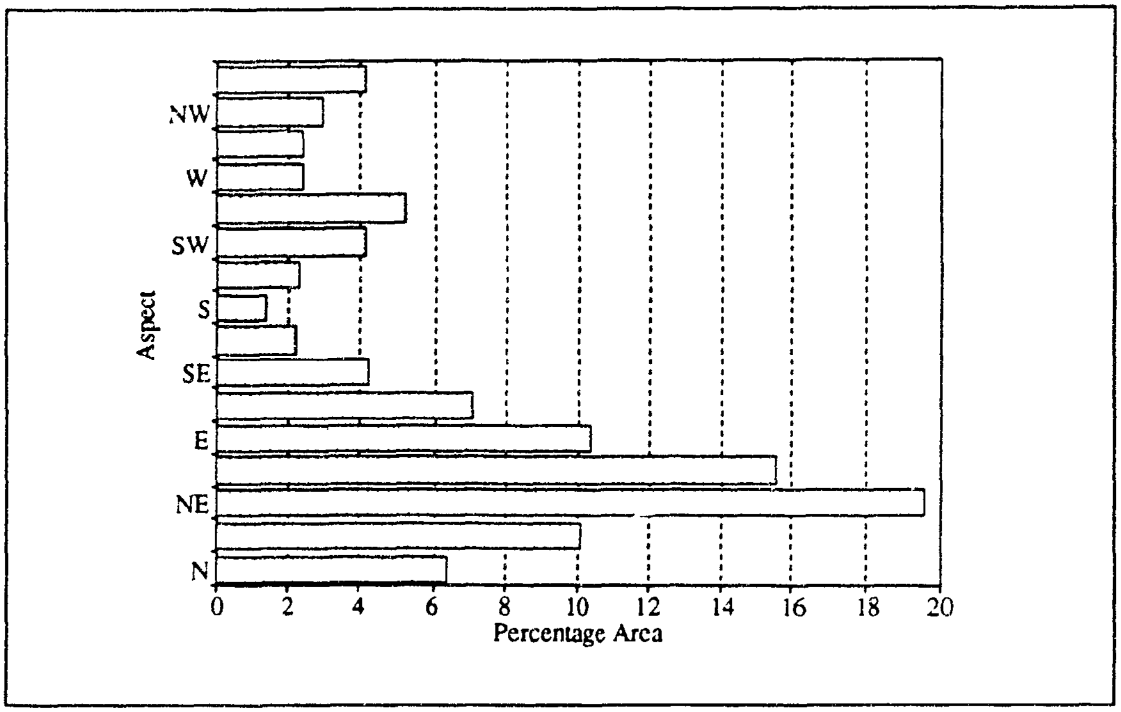


Figure 5.3: Orientation of Avalanche Tracks

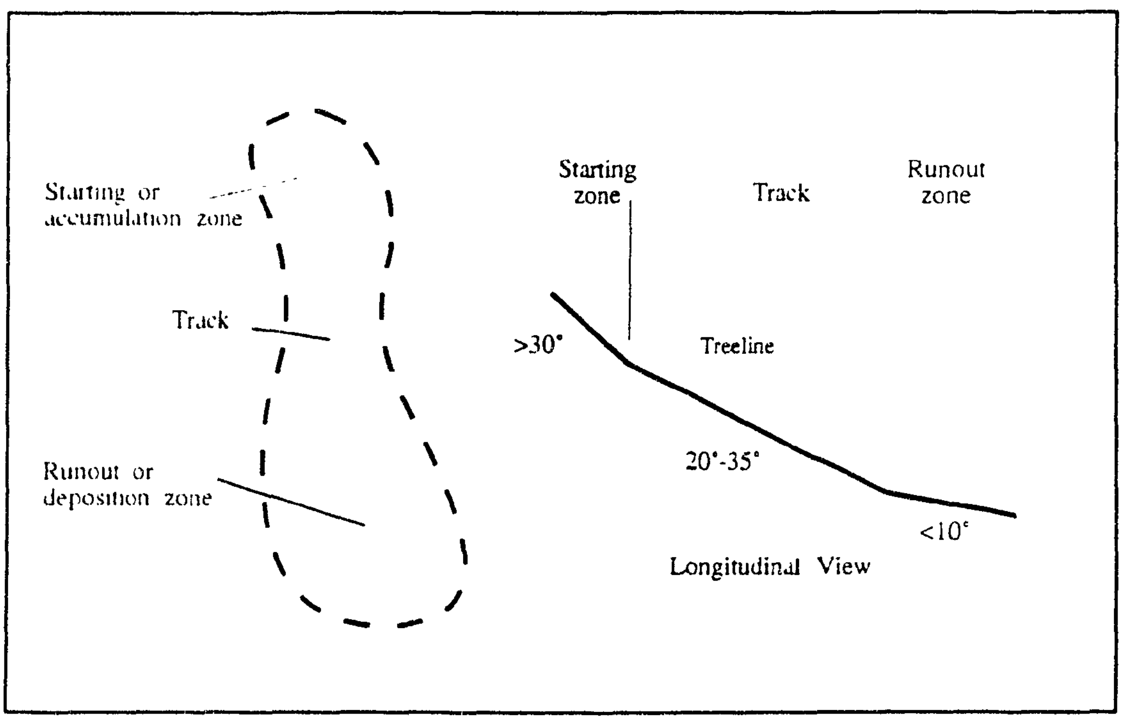


Figure 5.4: Avalanche Slope Morphometry (from Gardner, 1981)

Indexing overlay Template

Original Classes	Avalanche Hazard Class	Index
Slope Layer	**Weight 50**	
0-5°	low	1
5-20°	medium	2
20-60°	high	3
60-75°	medium	2
>75°	low	1
Aspect Layer	**Weight 30**	
North	medium	2
North East	high	3
East	medium	2
South East	low	1
South	low	1
South West	low	1
West	low	1
North West	low	1
Elevation Layer	**Weight 15**	
1500m-1800m	low	1
1800m-2000m	medium	2
>2000m	high	3
Vegetation Layer	**Weight 5**	
Unvegetated	high	3
Grass Dominated	medium	2
Open Forest	medium	2
Dense Forest	low	1

Figure 5.5: Index Overlay Template

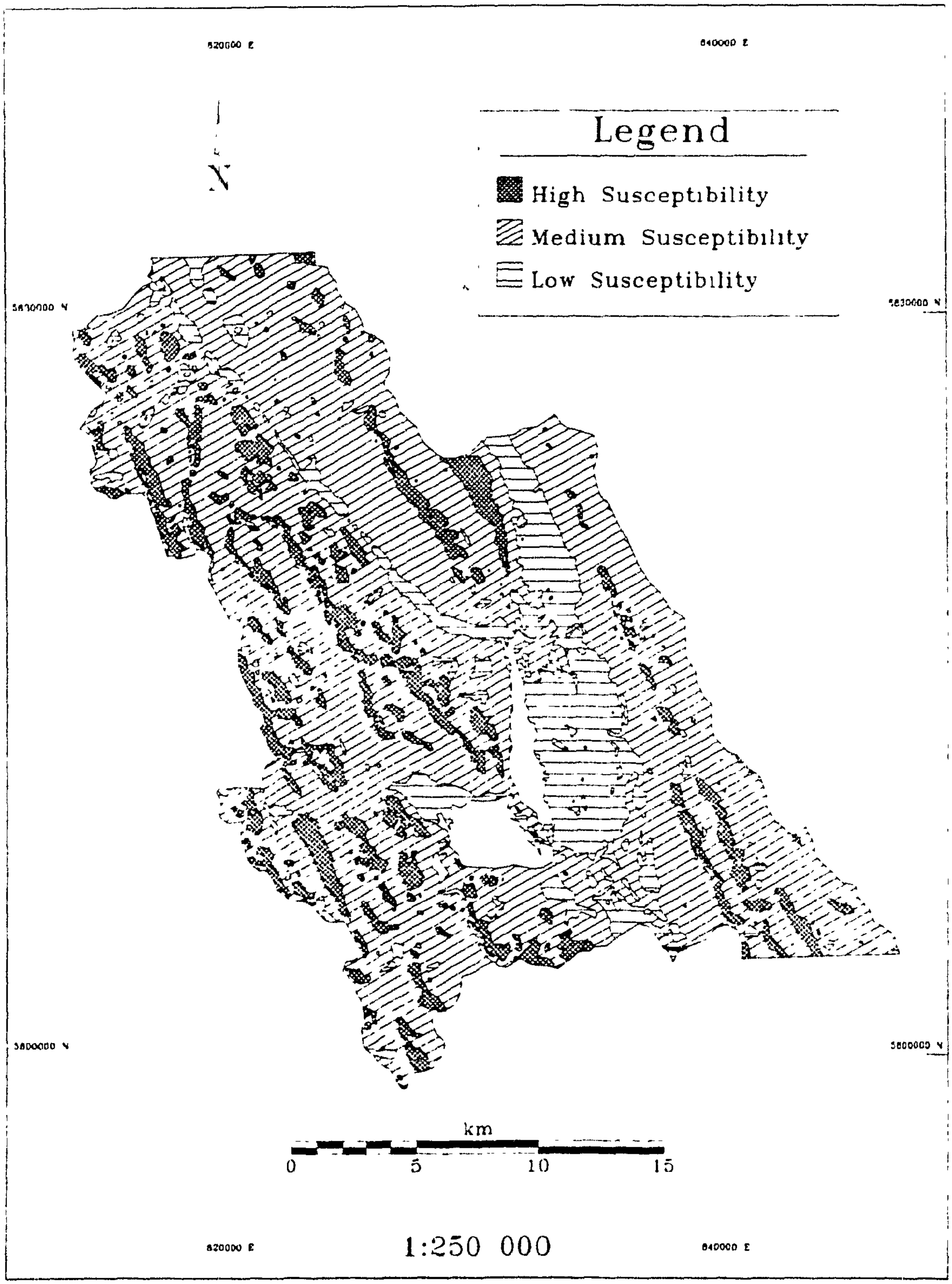


Figure 5.6: Avalanche Susceptibility Map

5.1.2 Forest Fires

This study deals with the assessment of fuel sources in the area, and in association with other variables, attempts to quantify the fire hazard. It must be noted, though, that this assessment is concerned with the potential fire hazard at any particular location, rather than the spread of fire, which is beyond the scope of this research.

All burned areas were cross tabulated with elevation, slope, aspect, and proximity to hydrology data sets. Burns from the 1990 vegetation map were overlayed with the 1978 vegetation map to identify the vegetation type the fires occurred on. This was not possible for the 1978 data, as earlier vegetation maps were not obtained. Figure 5.7 illustrates the elevational distribution of burned areas, with the largest percentage having occurred in the 1800m to 2300m band. This corresponds to areas which contain moderate to densely forested areas. Slope gradients between 15° and 40° have the highest percentage of burns, which is also the case with south westerly facing slopes, shown in Figures 5.8 and 5.9. The burned areas analyzed from the 1990 vegetation map, illustrate that they all occurred on Spruce-Alpine Fir forest. Occurrence of roads, trails, and watercourses are considered to aid in the suppression of fire hazard, since the primary objective at the stage is to evaluate the fire hazard based on potential fuel. Although the data representing forest fire occurrence is limited, there are still some strong associations found, especially between slope and aspect.

For the purpose of this study, the following variables are used: Vegetation type, elevation, slope, aspect, proximity to water courses, and occurrence of roads and trails. These variables were then weighted according to their importance as influential factors in forest fire occurrence. The weights were assigned as follows:

Vegetation	65%
Slope	20%
Aspect	5%
Roads/Trail	4%
Hydrology	4%
Elevation	2%

Vegetation receives the largest weight, reflecting its importance as a potential fuel source. Slope is also considered to be a significant factor in fire occurrence, whereas proximity to roads, trails, and watercourses receive a minor weight, reflecting their secondary importance. The same is true of elevation, which is assigned a minimal weight to represent it as a factor, but to a lesser degree. These weights attempt to identify the variables involved with fire occurrence in a hierarchical manner, allowing vegetation type to take precedent over all other variables. The classes within each data set were then ranked to incorporate their relative importance in the fire hazard model. These classifications are illustrated in Figure 5.10, representing the index overlay template used to create the fire hazard susceptibility map. Vegetation was ranked into the following categories: dense and moderately dense pine forest were assigned an index of 3, representing high potential. Open pine forest, dense and moderately dense shrub assigned an index of 2, representing moderate potential. Sparse shrub, grass land, herb dominated, and lichen/bryophyte dominated received an index of 1, representing a low potential. Unvegetated areas were assigned an index of 0, indicating no potential for fire hazard. Slopes with a gradient less than 5° were assigned an index of 1, between 5° and 20° an index of 2, and above 20° an index of 3. These classes were established by analyzing changes in the slope frequency graph, and partly from other research sources (Brass *et al.* (1983) report 20° as a crucial threshold in fire hazard).

Aspect was divided into northerly and easterly (315° through 135°), southerly (135° through 225°), and westerly (225° through 315°). Gardner *et al.* (1983) indicates that over 65% of the mean daily winds are from the south west to north west (225° through 315°). Aspect in this range was assigned an index of 3, recognizing the importance of wind as a contributing factor to fire hazard. Southerly aspects were assigned an index of 2, recognizing their higher insolation potential. Northerly and easterly aspects were assigned an index of 1. Occurrence of water courses, roads, and trails was incorporated into the assessment by creating corridor buffers around these linear features. Main rivers were assigned buffers of 10m, whereas minor rivers assigned buffers of 5m. This was also applied to roads and trails, recognizing that there will generally be less vegetation around major roads or rivers than minor ones. Areas within the 5m buffer for minor rivers and trails were assigned an index of 2, and outwith the buffer an index of 3. In the case of major rivers and roads, an index of 2 was assigned to areas within the 10m buffer, and again, an index of 3 for areas outwith the buffer. This recognizes a lesser degree for fire potential in close proximity to these features, and compensates for lack of detail on the vegetation maps, which do not identify these breaks in the vegetation. Elevation was divided at the 2000m level, with areas above assigned an index of 2, and areas below an index of 3. This was chosen because it represents a break point in the elevation frequency graph, and it also represents the upper limits of the vegetation.

Figure 5.11 illustrates the forest fire hazard map generated from these classifications. Over 30% (157km^2) of the area is considered to have a high potential for forest fire occurrence, representing a significant proportion of the park. As would be expected, these areas occupy the lower elevations and steep sided valley slopes, due to the abundance of vegetation. Of the remaining area, 17% (86km^2) is regarded as having medium susceptibility, 49% (239km^2) low susceptibility, and 2% (11km^2) as being under no threat at all.

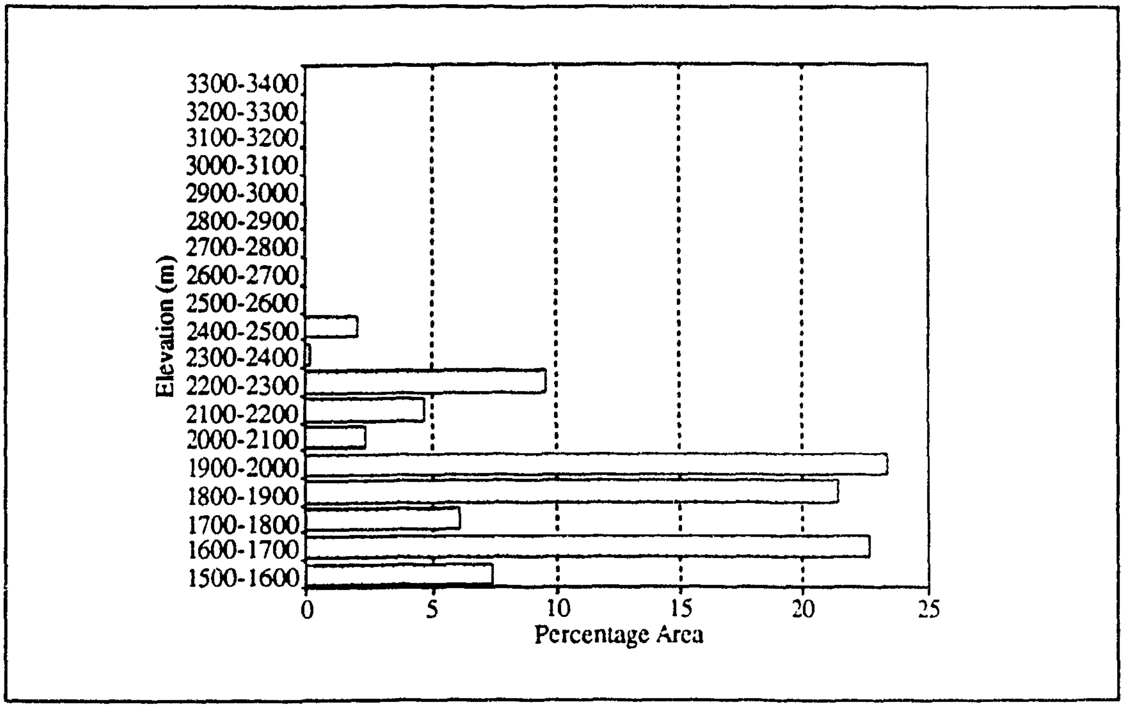


Figure 5.7: Elevational Distribution of Burned Areas

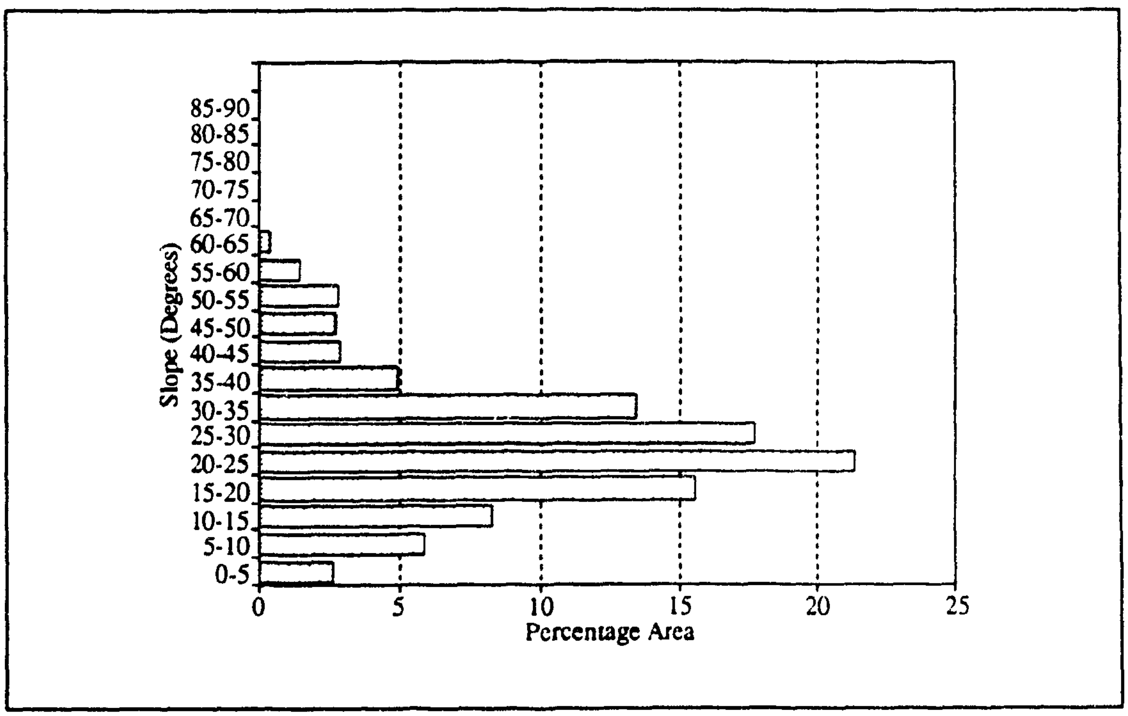


Figure 5.8: Slope Distribution of Burned Area

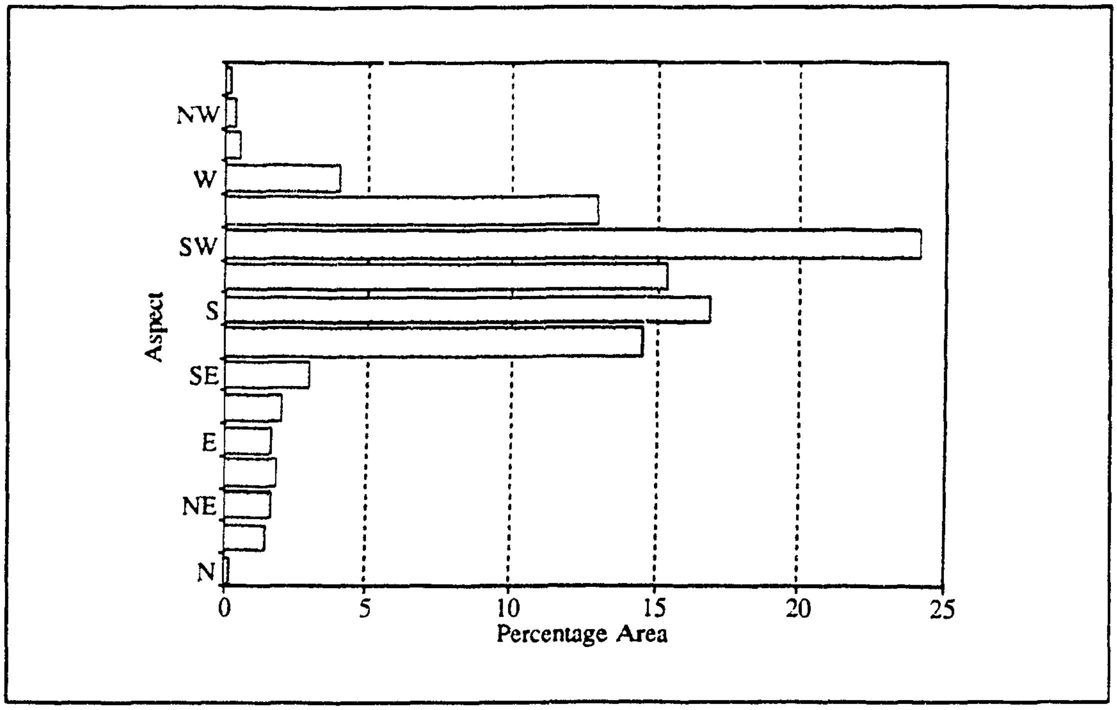


Figure 5.9: Aspect Distribution of Burned Areas

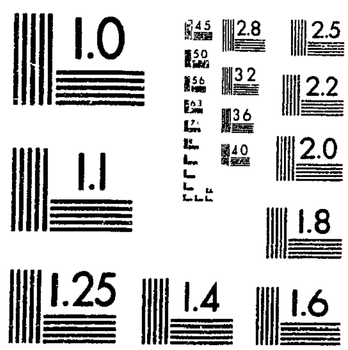
Indexing overlay Template

Original Classes	Fire Hazard Class	Index
Vegetation Layer	**Weight 50**	
Dense Pine	high	3
Moderately Dense Pine	high	3
Open Pine	medium	2
Dense Shrub	medium	2
Moderately Dense Shrub	medium	2
Sparse Shrub	low	1
Grassland	low	1
Herb Dominated	low	1
Lichen/Bryophyte	low	1
Unvegetated	none	0
Slope Layer	**Weight 20**	
<5°	low	1
5-20°	medium	2
>20°	high	3
Aspect Layer	**Weight 5**	
North	low	1
North East	low	1
East	low	1
South East	medium	2
South	medium	2
South West	high	3
West	high	3
North West	high	3
Roads/Trails	**Weight 4**	
0-10m (from feature)	medium	2
>10m	high	3
Hydrology	**Weight 4**	
0-5m (from feature)	medium	2
>5m	high	3
Elevation Layer	**Weight 2**	
<2000m	high	3
>2000m	medium	2

Figure 5.10: Index Overlay Template (Forest Fires)

2 of/de 2

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT



PRECISION[SM] RESOLUTION TARGETS

PIONEERS IN METHYLENE BLUE TESTING SINCE 1974

Micro D

15000 COUNTY ROAD 5 BURNSVILLE MN 55337 USA
TEL 612 435 7667 FAX 612 435 7657 TLX 5106009488

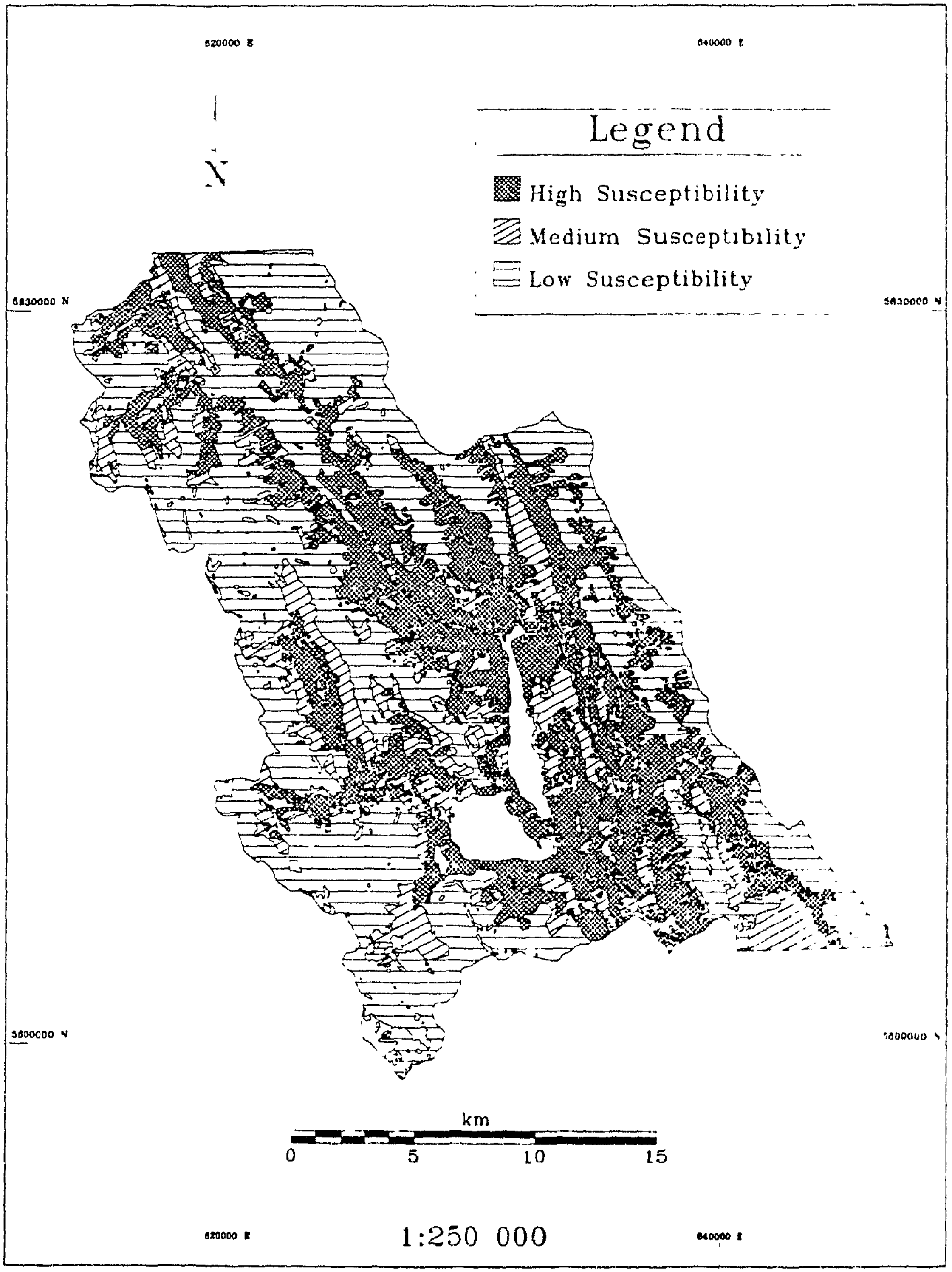


Figure 5.11: Forest Fire Hazard Potential

5.1.3 Rockslides/Rockfalls

For the purpose of this research, the analysis is limited to rockslide and rockfall hazard, and does not consider other closely related processes such as landslides or debris flows. It is the aim of this assessment to identify environmental associations thought to be important in initiating or triggering such events, but detailed analysis regarding rock slope mechanics, climatological factors, and frequency calculations, is beyond the scope of this research.

Figures 5.12 through 5.15 represent the percentage distribution of rockslides/rockfall deposits with respect to elevation, slope, aspect, hydrology and thrust faults. Cross tabulation with elevation reveals that all of the mapped occurrences lie within the 1900-2800m band. In the case of the slope frequency graph, rockslide/rockfall occurrences are seen to occur on slopes up to 75°, with the largest proportion in the 0-30° range. It would be expected that steeper slopes would reveal the largest frequencies of rockslides/rockfalls, but due to the mapping methods this is not the case. Most of the events mapped are identified from the debris that is created from the rockslide/rockfall process, thus settling on less steep ground. Aspect distribution reflects the major NNE-SSW trend of the valleys sides, with north easterly aspects having the highest frequencies (35%).

Deposits reflecting high magnitude rockslope failure are derived mainly from the limestones of the Rundle group (35% of all occurrences), and are found at the base of scarp slopes. The Palliser (18%) and the Kootenay group (12%), combined with the Rundle limestones, account for three quarters of all the occurrences mapped. The majority of deposits are located in situations that are favourable to ice accumulation, at high elevations and with north easterly aspect, and were likely sites of glacier build up during the Crowfoot episode. Thus, north easterly facing slopes appear to be most conducive to rockslide/rockfall occurrence. The highest rates at present occur on high free faces with north easterly aspects, the same slopes noted as scarp and lee slopes which accumulate and maintain snowcover (Gardner *et al.*, 1983).

Distance from major thrust faults and watercourses was taken into consideration, but no obvious relationship was revealed. In the case of thrust faults, the frequency of occurrence increases with distance, with over 50% of the rockslides/rockfalls occurring over 1km away. Distance from major watercourses provides little evidence of water playing an active role in initiating rockslides/rockfalls, although this is known not to be the case. Approximately 50% of occurrences are within 500m of watercourses, and the remaining between 500m and 2km. This analysis fails to identify ephemeral or intermittent flowing streams, which are believed to be an influential factor in the process of rockslide/rockfall initiation. One would expect a better relationship to occur between occurrence and distance if data of this type had been incorporated.

From the analysis carried out, in conjunction with similar research of this nature, the factors associated with rockslide/rockfall occurrence would appear to be steep slopes, free faces of structural and erosional origin, rundle formation limestones and dolomites, north easterly aspect, higher elevations, and presence of water courses. The data sets used to create the rockslide/rockfall susceptibility map were weighted as follows.

Slope	40%
Geology	30%
Aspect	25%
Elevation	3%
Hydrology	2%

Slope receives the largest weighting, with geology and aspect of secondary, but significant importance. Elevation and proximity to watercourses are represented in the analysis, but of minimal importance to the final results. Again, the weights are assigned on a hierarchical basis, whereby each data set is more important in determining the final results than the one below it. If elevation meets the criteria required, it still doesn't mean that the area is prone to rockslide/rockfall hazard, unless the aspect, geology, and slope are of the required values. The same applies to aspect, whereby the area could have a north easterly aspect, but unless it meets the criteria of geology and slope, then it won't be identified as having a high susceptibility rating.

Figure 5.16 illustrates the index overlay template used to produce the susceptibility map. Slopes between 0 and 5° were assigned a value of 1, between 5 and 15° a value of 2, despite the results obtained from the slope frequency graph, and slopes greater than 15° a value of 3. From the bedrock geology map, areas in the Rundle group received a value of 3, areas in the Palliser group a value of 2 and all others a value of 1, representing the higher rates of occurrence on the limestones and dolomites. Areas with north easterly aspects were assigned a value of 3, south westerly a value of 2, and the remaining categories a value of 1. Elevations above 2200m were assigned a value of 3, and below, a value of 2. This represents a break in the elevation frequency graph, and also represents the likelihood of more intense physical weathering at higher altitudes. Distance from major watercourses was also included, with areas within 500m of a watercourse receive a value of 3, and greater than 500m a value of 2.

The resultant map is shown in Figure 5.17, with 12% (58km^2) of the area having a high susceptibility to rockslide/rockfall occurrence. Over two thirds of the area (67% or 333km^2) is considered to have medium susceptibility, and the remaining 21% (103km^2) low susceptibility.

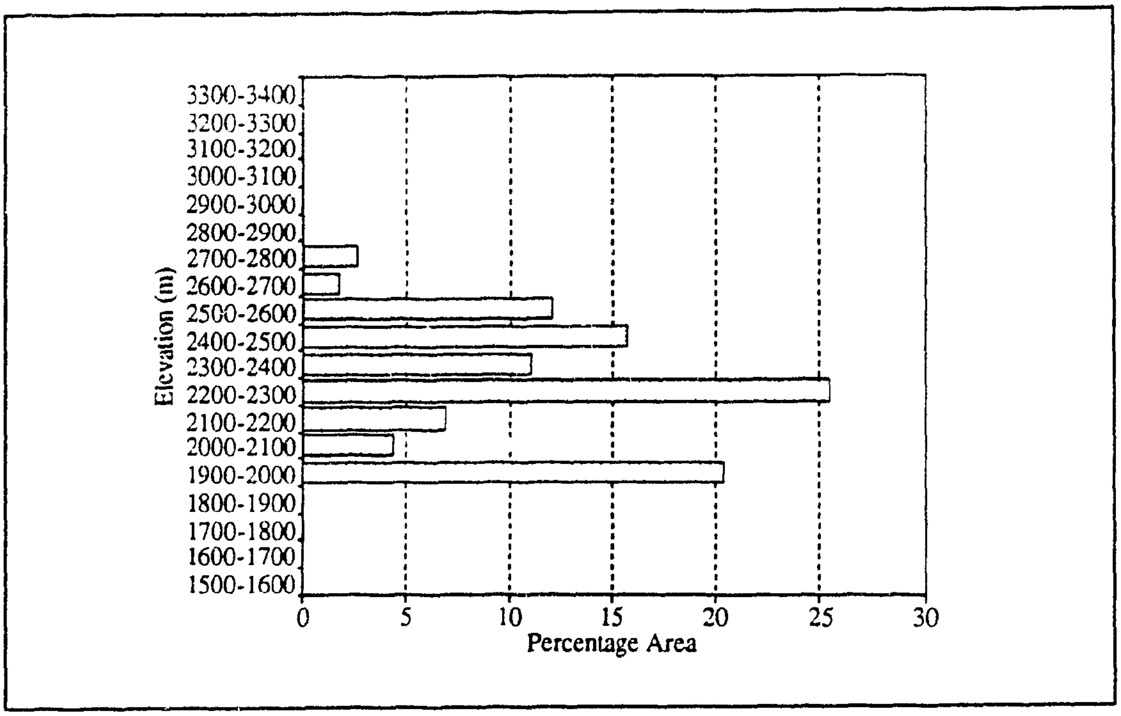


Figure 5.12: Elevational Distribution of rockslides/rockfalls

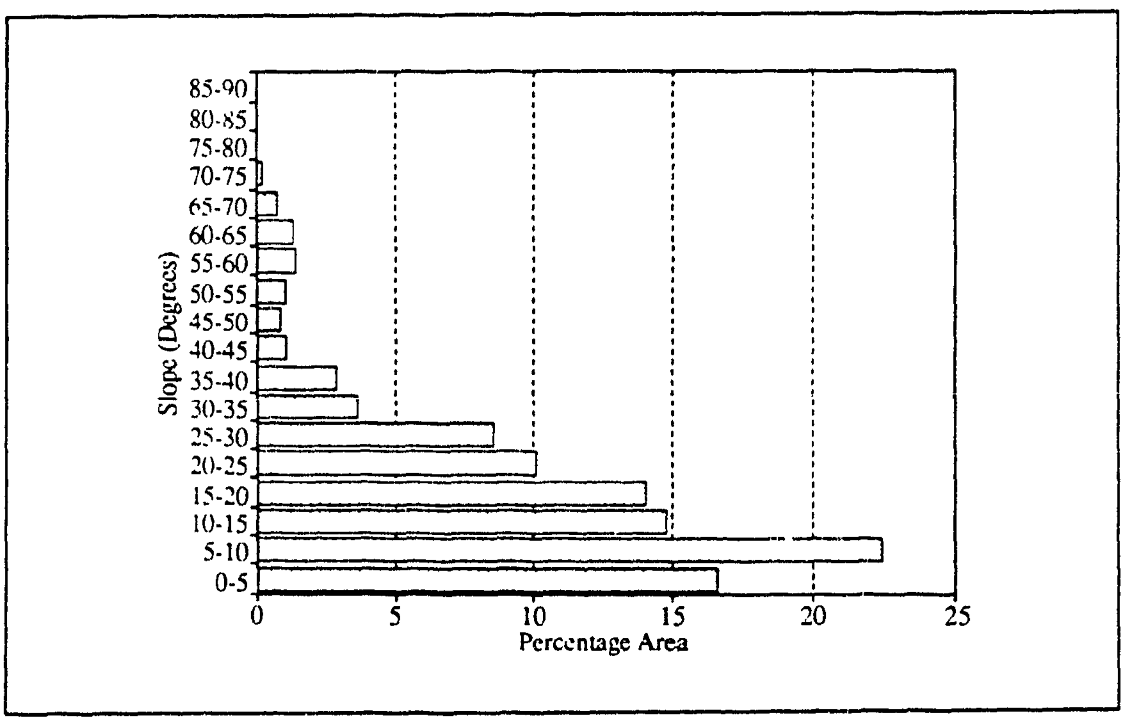


Figure 5.13: Slope Distribution of rockslides/rockfalls

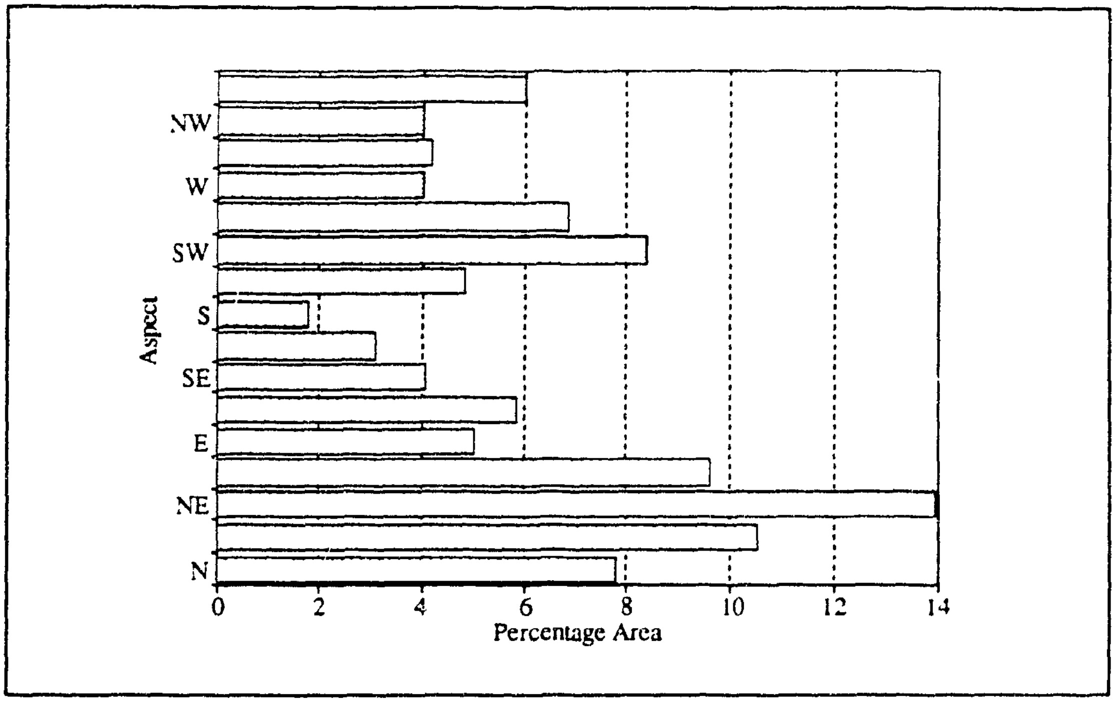


Figure 5.14: Aspect Distribution of rockslides/rockfalls

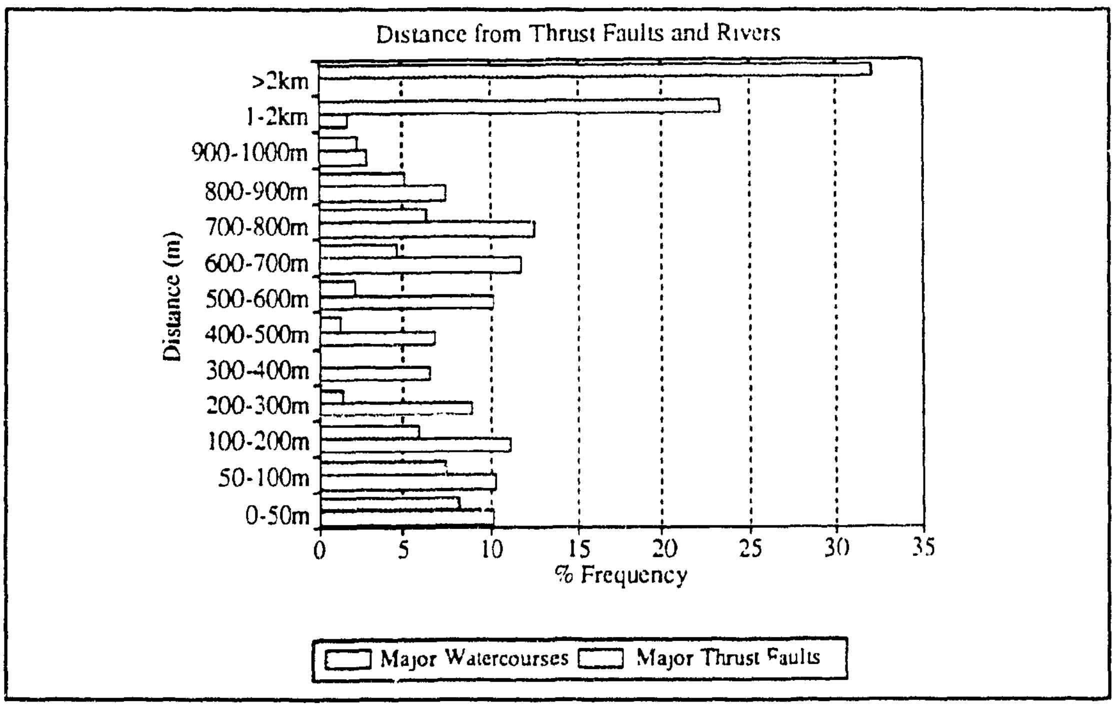


Figure 5.15: Proximity to major watercourses and thrust faults

Indexing overlay Template		
Original Classes	**Rockslide/fall Hazard Class**	**Index**
Slope Layer	**Weight 40**	
0-5°	low	1
5-15°	medium	2
>15°	high	3
Bedrock Geology Layer	**Weight 30**	
Rundle	high	3
Palliser	medium	2
Others	low	1
Aspect Layer	**Weight 25**	
North	medium	2
North East	high	3
East	medium	2
South East	low	1
South	low	1
South West	medium	2
West	low	1
North West	low	1
Elevation Layer	**Weight 3**	
<2200m	medium	2
>2000m	high	3
Hydrology	**Weight 2**	
<500m	high	3
>500m	medium	2

Figure 5.16: Index Overlay Template (Rockslides/rockfalls)

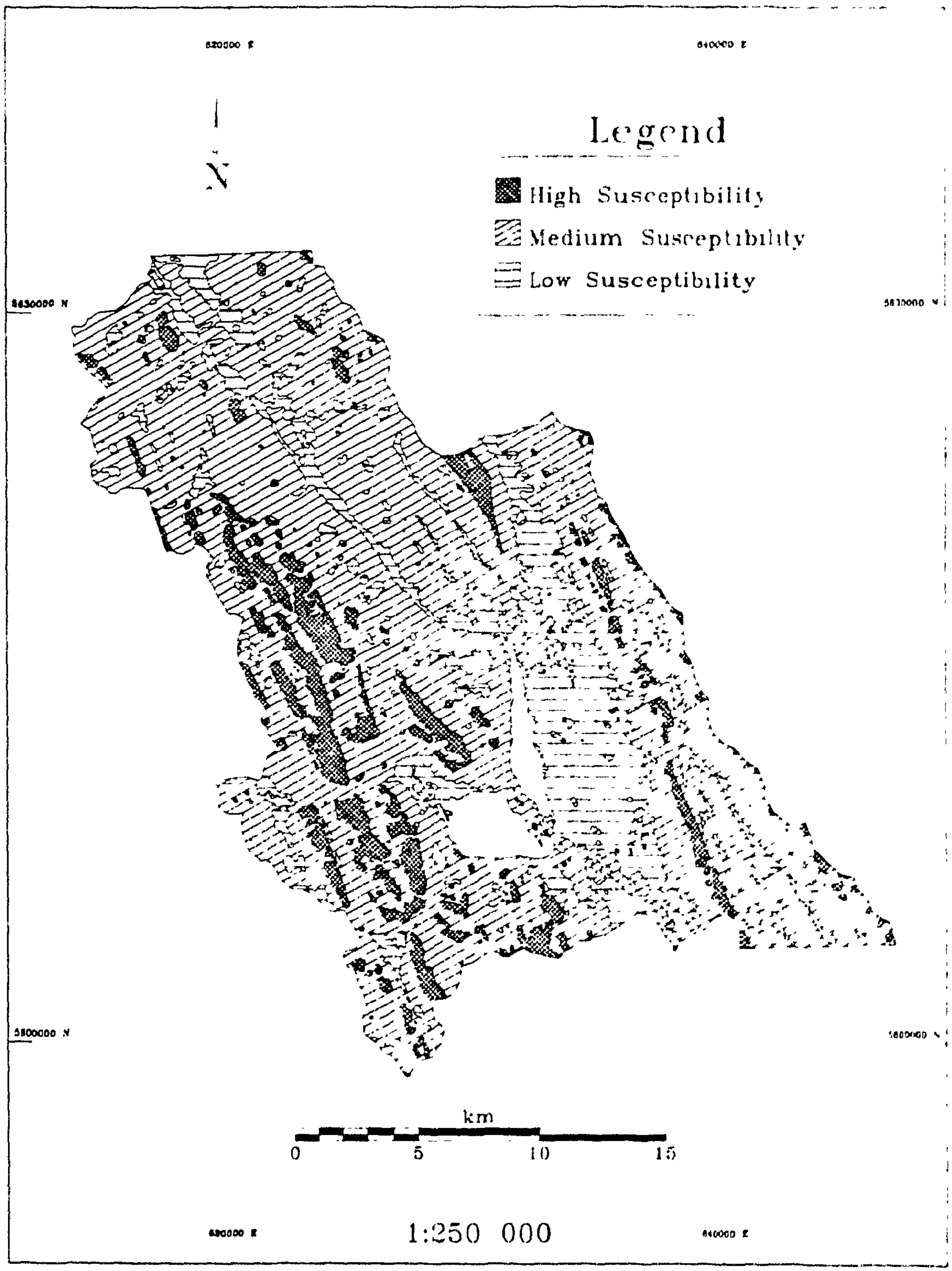


Figure 5.17: Rockslide/rockfall Susceptibility Map

5.1.4 Floods

Flood related areas were cross tabulated with elevation, slope, aspect, bedrock geology, and distance from major rivers and lakes, with the results illustrated in Figures 5.18 through 5.21. Over 75% of the flood related areas occur in the 1500m to 2000m elevational band, with the upper most elevation being 2400m. This is a direct result of the increased drainage with lower elevations. Although the results suggest that no flooding occurs at higher elevations, this is not always the case. Flash floods and torrents may well occur in the upper elevational bands, but due to the steeper slopes generally experienced, these areas are not conducive to prolonged flooding. Over 55% of the flood plains occur on slopes with a gradient less than 5°, and 85% on slopes with a gradient less than 10°. There appears to be no association with aspect, as would be expected of the relatively flat valley bottoms, where most flooding occurs. When cross tabulated with bedrock geology, over 65% of the flood related areas occurred on the Fernie and Spray River formations. These formations are especially prone to weathering, and consequently are commonly associated with valleys and passes. No strong association with vegetation is revealed, with a relatively even distribution over the lower elevation vegetation types. The most significant value was found to be related to Spruce-Alpine Fir forest, with this type of vegetation occurring on over 20% of the identified flood plains, suggesting its tendency to inhabit the fertile land in these areas. As would be expected, a strong association was found between frequency of flood related areas and distance from major rivers and lakes. The results show that over 80% of the mapped areas lie within 200 metres of rivers and lakes, and all within the 900 metre mark.

In summary, flood related areas appear to be influenced primarily by slope, elevation and proximity to major lakes and rivers. Aspect can be regarded as being irrelevant, and bedrock geology as having a minor role. Spray River and Fernie formations are found mainly in the valley bottoms as mentioned, and although an indicator of flood susceptible areas, do not influence the process. The data was weighted in the following manner to create a flood hazard susceptibility map:

Proximity to Rivers and Lakes	50%
Slope	45%
Elevation	4%
Bedrock Geology	1%

The same argument can be applied to the weighting schemes as previously discussed, whereby the data sets are arranged hierarchically to determine flood susceptible areas. As stated, bedrock geology appears to be an indicator of flood related areas, but does not influence the process, therefore the minimal weight of 1% will not identify any areas as being highly susceptible unless the other conditions are met. The same applies to elevation, but slope and proximity to rivers and lakes carry the most influence in the analysis. The weights suggest that any areas within a certain distance of rivers and lakes, and with a particular slope, will be highly susceptible to flooding.

The index overlay template is illustrated in Figure 5.22, with classifications as follows. Areas within 100 metres of rivers and lakes were assigned an index of 3, between 1 and 200 metres an index of 2, between 200 and 900 metres an index of 1, and areas greater than 900 metres an index of 0, suggesting no flood hazard at this distance. Slopes between 0-5° were assigned an index of 3, between 5-10° an index of 2, between 10-20° an index of 1, and areas with slope gradients greater than 20° an index of 0. Elevations between 1500-2000 metres were assigned an index of 3, between 2000-2400 metres an index of 2, and above 2400 metres an index of 1. As discussed previously, flood events may well occur at higher elevations and on steeper slopes, but prolonged flooding is unlikely and therefore these areas are ranked a having a low susceptibility. Areas representing the Spray River and Fernie formations were assigned an index of 3, and all others an index of 2, recognizing it as an indicating factor.

Figure 5.23 illustrates the flood hazard susceptibility map created, with 8% (40km^2) of the area having a high susceptibility to flood hazard, 32% (160km^2) medium, 56% (276km^2) low, and 4% (20km^2) having no susceptibility at all.

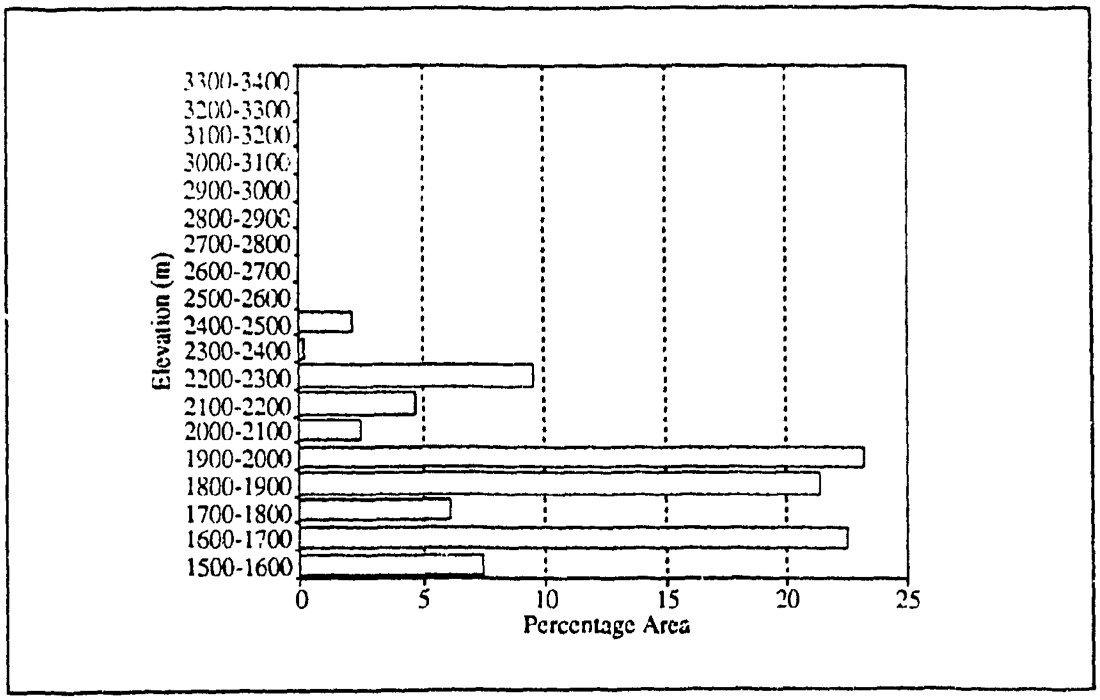


Figure 5.18: Elevational Distribution of Flood Related Areas

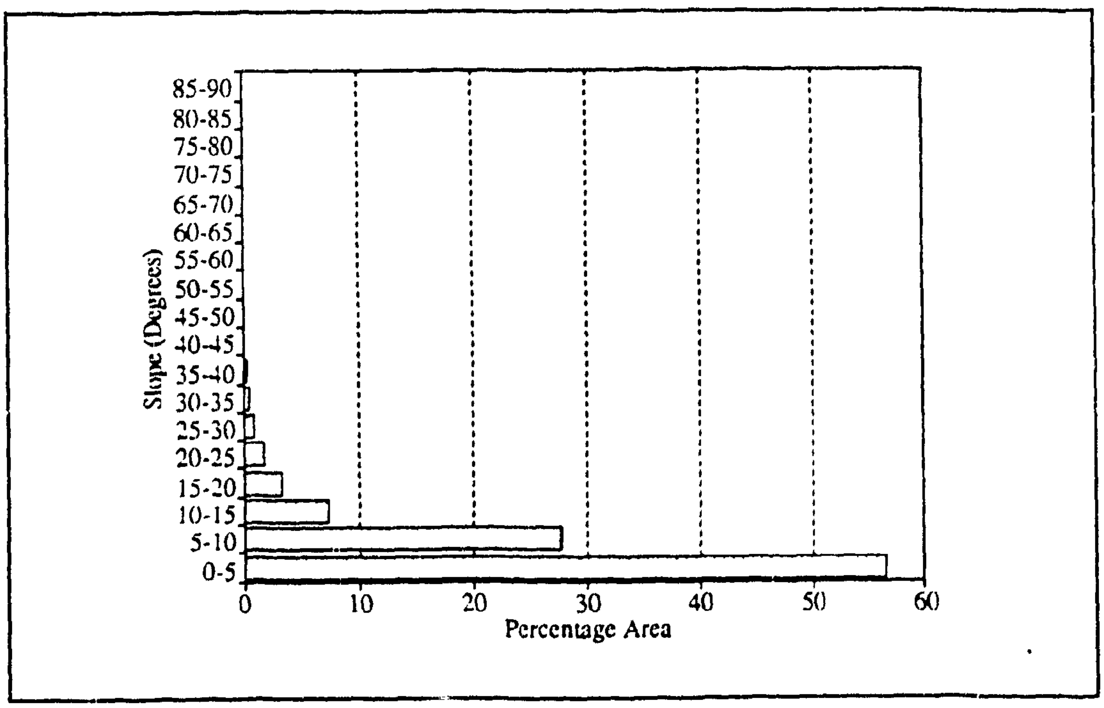


Figure 5.19: Slope Distribution of Flood Related Areas

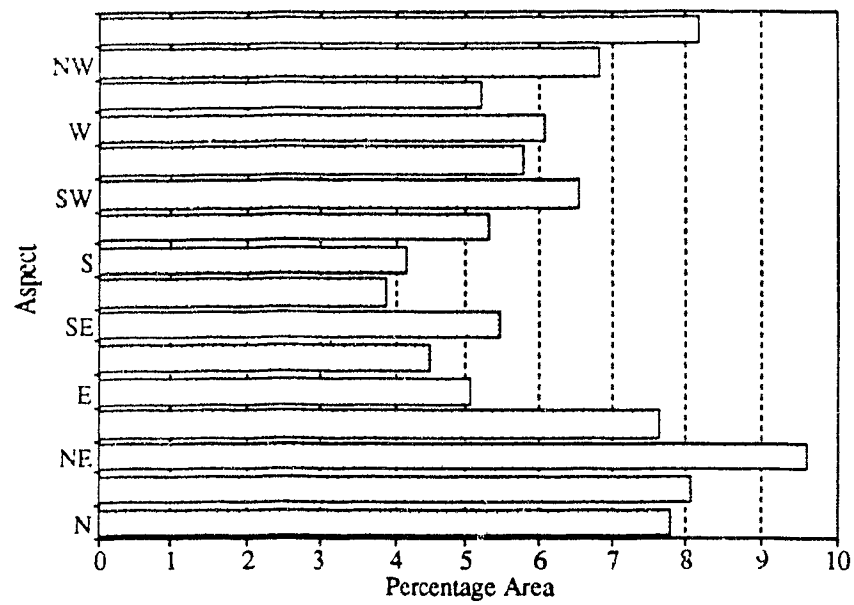


Figure 5.20: Aspect Distribution of Flood Related Areas

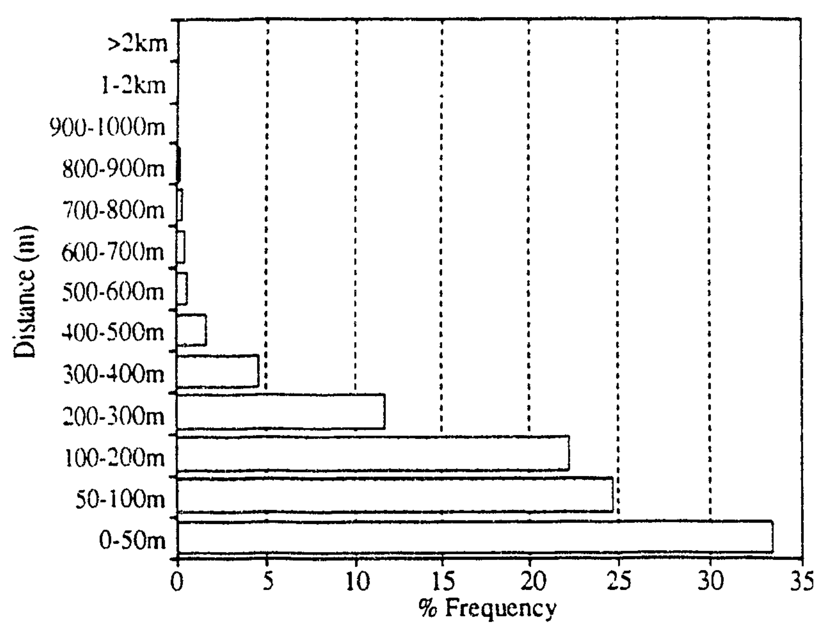


Figure 5.21: Proximity of Flood Related areas to Rivers and Lakes

Indexing overlay Template

Original Classes	Flood Hazard Class	Index
Proximity to Rivers and Lakes	**Weight 50**	
0-100m	high	3
100-200m	medium	2
200-900m	low	1
>900m	none	0
Slope Layer	**Weight 45**	
0-5°	high	3
5-10°	medium	2
10-20°	low	1
>20°	none	0
Elevation Layer	**Weight 4**	
1500-2000m	high	3
2000-2400m	medium	2
>2400m	low	1
Bedrock Geology Layer	**Weight 1**	
Spray River	high	3
Fernie	high	3
Others	medium	2

Figure 5.22: Index Overlay Template (Floods)

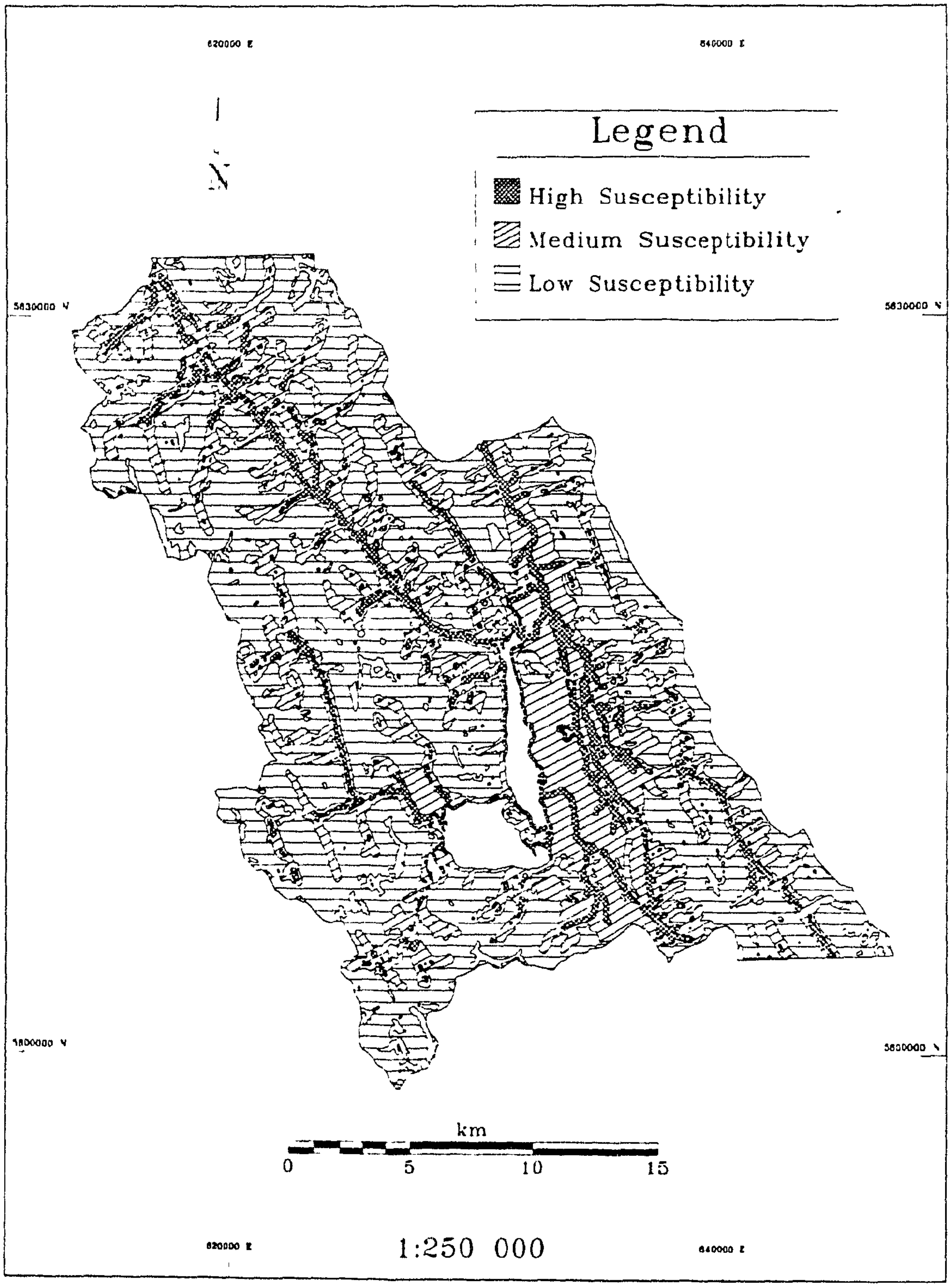


Figure 5.23: Flood Hazard Susceptibility

5.2 Risk Estimation

The risk estimation process involves two stages, that of potential risk estimation, and of actual risk estimation. Potential risk can be defined as the total risk entailed at any one point from the hazards identified. It takes into consideration only the physical processes involved and assesses the degree of risk from these processes. Actual risk, on the other hand, takes into consideration the potential risk from the physical processes and relates it to the human activity in the area, thus attributing a meaning to the risk. The analysis recognizes the highly temporal nature of both the physical processes and human activity in the area. The results are discussed, and the importance of the human dimension in the estimation of risk is assessed.

5.2.1 Potential Risk

Estimating the potential risk involves combining the susceptibility maps for each hazardous process, in a manner that reflects the relative frequency of each under a temporal framework. These maps are index overlayed and assigned weights to reflect the temporal nature of the processes. These weights are determined by analyzing secondary data relating to frequency of occurrence on an annual basis. It is also possible to incorporate diurnal fluctuations into the model, although detailed analysis at this level is not performed.

Each hazardous process has a preferential time of occurrence on a seasonal basis, and in some cases, even on a diurnal basis. Data relating to avalanche, forest fire, rockslide/rockfall, and flood frequency was analyzed to illustrate patterns in occurrence. Frequency data for avalanche occurrence was obtained from Gardner *et al.* (1981, 1983), forest fire occurrence from Hawkes (1979), rockslide/rockfall occurrence from Gardner *et al.* (1983), and flood occurrence from the discharge data. These secondary data sources provide indications as to the probability of occurrence at any time of the year. The method used attempts to quantitatively assess the probability of occurrence as accurately as possible, although it is recognized that a wealth of factors influence the occurrence of physical events, and that these are constantly changing. This method of assessment recognizes this fact by providing a technique whereby the criteria can be modified to take into consideration changing variables.

Avalanche frequency for various avalanche tracks in the park were studied using time lapse photography during the winter season of 1982/83 by Gardner *et al.* (1983). The highest rates of occurrence are related to the months of March, April, and May, and were dominated by thaw induced, wet snow avalanches. A rapid drop obviously occurs during the summer months, although avalanche occurrence has been noted at high elevations where snow or ice remains throughout the year (Gardner *et al.*, 1983). The frequency then increases again into the winter months. Diurnal frequencies are also noted, with occurrence more likely when slopes receive direct sunlight. Forest fire frequency obviously increases during the dry summer months, with June, July, and August having the highest rates of occurrence (Hawkes, 1979). Rockslide/rockfall frequencies were measured by Gardner *et al.* (1983) for the Highwood Pass area of the park, concluding that there were no apparent trends during the period of study (June-September). However, without data for the remainder of the year, it is difficult to quantitatively assess the temporal distribution of rockslide/rockfall. It was noted though, that occurrences are more likely during the middle of the day and early afternoon than any other time, based on observations over a three year period. Flood frequency has been documented in the near vicinity by Gardner (1981), with occurrences more likely during the spring melt. Discharge data was analyzed to illustrate peak flows, shown in Figure 5.24, suggesting flood frequency to be most likely during the months of June, July, and August.

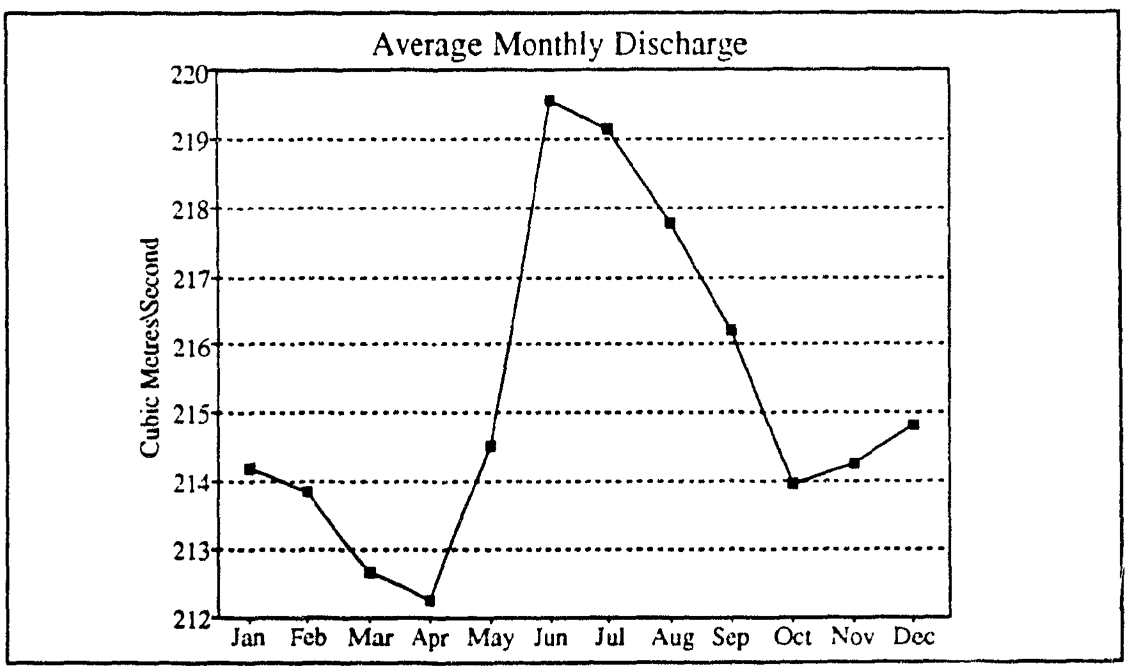


Figure 5.24: Average Discharge for all Gauging Stations

Depending on the time of year, each hazard susceptibility map is assigned a weight representing its probability of occurrence. Table 5.1 illustrates the weighting scheme used in the assessment. The values derived are based on a simplistic high (3), medium (2), and low (1) scale of probability, mainly due to the lack of quantitative frequency data available. Index overlay templates relating to each month are created using these weighting schemes, and then used to create potential risk maps for any particular time of the year. This is an interactive process whereby the user selects the index overlay template relating to the month of interest and the model calculates the risk based on these criteria. These index overlay templates may be modified to reflect changes in conditions (for example increased precipitation which may lead to increased probability of flooding) or incorporate new variables, and the risk map re-created to reflect the changes. It must also be noted, that the actual hazard susceptibility maps used in this procedure may be re-created using different criteria to reflect changes in conditions or factors not previously taken into consideration. For example, forest fire occurrence or logging in the area removes areas of vegetative cover, leading to more exposed slopes, which could subsequently be considered more prone to avalanche occurrence. This can be incorporated into the model by delineating these areas as non-vegetated and re-creating the susceptibility map, taking the change in the data into consideration. This allows for the effects of physical or human processes that influence the assessment to be accounted for, thus providing a responsive model to hazard occurrence in the area. Table 5.1 illustrates the weighting scheme used in risk estimation process.

	J	F	M	A	M	J	J	A	S	O	N	D
Avalanches	2	2	3	3	3	2	1	1	1	1	2	2
Forest Fire	1	1	1	2	2	3	3	3	2	2	1	1
Rockslides/.	2	2	2	2	2	2	2	2	2	2	2	2
Floods	1	1	2	3	3	2	2	2	2	1	1	1

Table 5.1: Potential Risk Weighting Scheme

These weights attempt to represent the temporal nature of each hazard, but are recognized as being rather simplistic. In the case of rockslides/rockfalls, lack of detailed frequency data meant that no distinction was made between the different months of the year, and an average value of 2 was assigned to that hazard. The other weights were assigned based on the previous discussion.

Figure 5.25 illustrates the potential risk for avalanche, forest fire, rockslide/rockfall, and flood occurrence for the month of August. It is evident that only a small proportion (<1%) of the study area is under a high degree of risk from hazardous processes, and that most of these areas are not within close proximity of areas of human activity. A large proportion of the park is, however, considered to be under a medium degree of risk (65%). This method of taking into account both the spatial and temporal nature of hazard occurrence, provides a valuable approach for determining the risk in the study area.

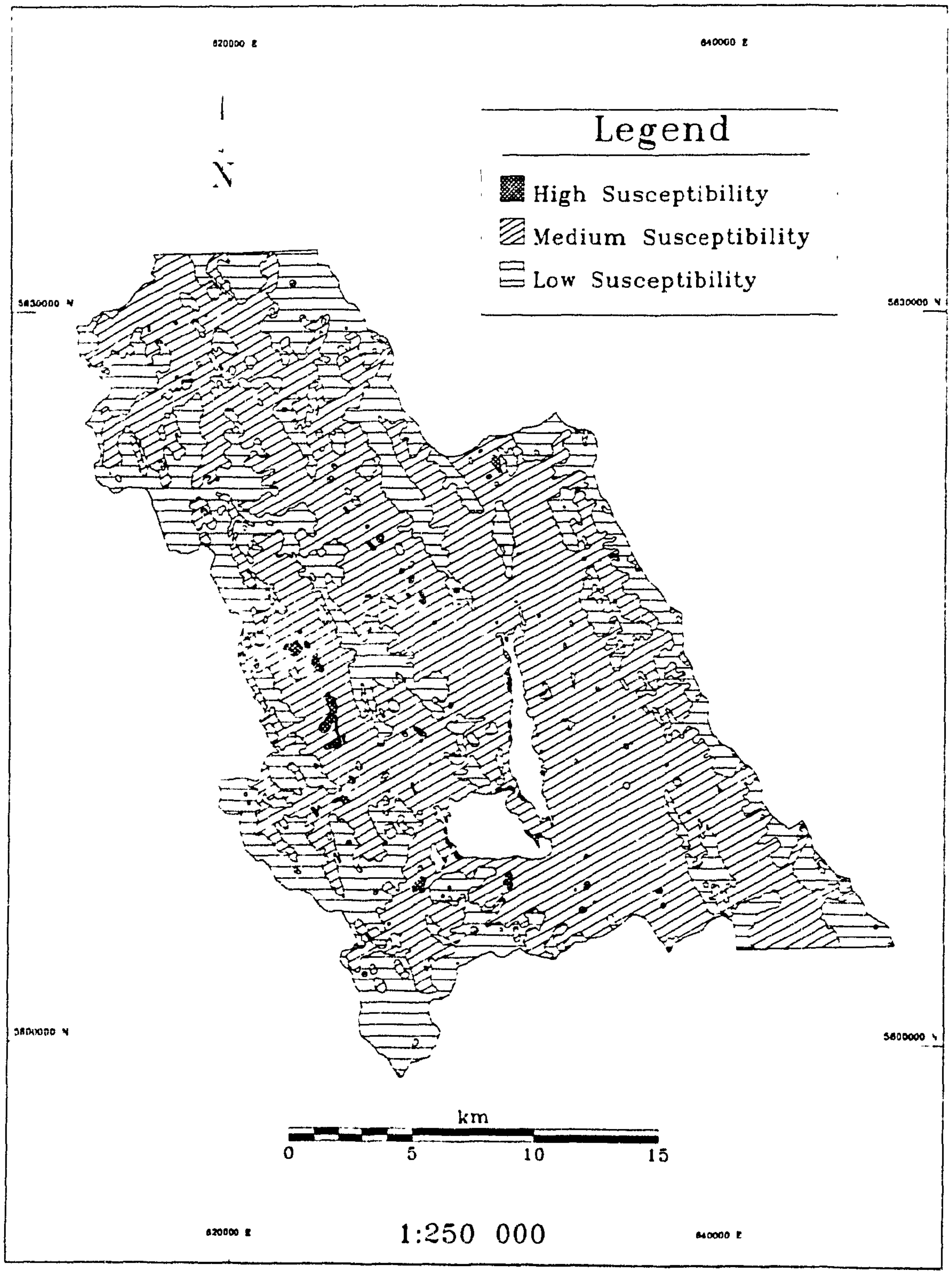


Figure 5.25: Potential Risk during August

5.2.2 Actual Risk

The actual risk maps created illustrate the degree of risk from the physical processes, regardless of the human component involved. It provides a measure of the potentially hazardous areas within the park, but does not attribute a meaning to the risk. This can be achieved by combining the absolute risk maps with the data relating to human activity to produce an estimation of the actual degree of risk.

Actual risk takes into consideration the consequences of the hazardous events, that is, the vulnerability of the persons or structures at risk. Analysis of campsite, road, trail, and day use facility data provides an indication of the human activity in the area. Figure 5.26 shows the increase in use of the park facilities in general over the past 6 years, with a noticeable peak during the 1988 Winter Olympics, held in Kananaskis Country. Average monthly breakdowns of facility use during the past 6 years were calculated (Figure 5.27), giving a clear indication of the highly seasonal use of the park. Peaks occur during the months of July and August, with low points occurring in April and November.

The locations of campsites, trails, roads, and facilities, represent the most intensely used areas of the park. These features, stored as point and linear structures, were then buffered to represent the activity in these areas (Figure 5.28). Distance from the feature is taken to be inversely proportional to the amount of activity. The buffers are valued on a rank scale from 1 to 3, representing low through high activity, with areas immediately surrounding the campsite, facility, road, or trail location, assigned a value of 3. Buffer zones were created using the following classification:

0-50 metres	High Activity	(3)
50-100 metres	Medium Activity	(2)
100-500 metres	Low Activity	(1)
>500 metres	No Activity	(0)

The buffered zones are not entirely accurate in that they do not take into account physical barriers that may influence human activity, such as excessively steep slopes. The buffers assume even dispersion of activity in a radial manner. In addition, the buffer zone values are derived from arbitrary classifications. This is a shortcoming of the model which is recognized along with other problems in chapter 5. Nevertheless, this indication of activity takes into consideration the highly temporal nature involved, with buffers being created around certain trails and facilities to represent the time of year and the type of activity. For example, during the winter months, more activity is to be expected on cross-country ski trails and ski slopes, whereas certain facilities are not available during this time of year. Most of the backcountry campgrounds in the area are closed during the winter months, in addition to the Kananaskis Trail through the Highwood Pass. For present purposes, all of the facilities are used in the analysis to represent the month of August.

Once the classification schemes are created, this enables maps of human activity to be created relating to the time of year. Thus, indicators of activity on a low/medium/high scale are obtained which are combined with potential risk maps, taking into consideration the highly temporal nature of both. The recognition of both the physical processes and human activity provides for an estimation of the actual degree of risk. For any particular time of year, the susceptibility maps can be overlayed with the human activity maps to provide a map of actual risk with nine classes, ranging from low activity/low risk to high activity/high risk. Analysis of the actual risk map indicates that only a small proportion of the total area of the park has high activity coupled with high risk (0.1%), thus the results are not illustrated. The most significant results obtained relate to areas of low activity coupled with low risk, and high/medium activity couple with medium risk, collectively representing over 20% of the whole study area, and illustrated in Figure 5.29.

Comparisons between actual risk at different time of the year can be seen to differ, due to the different processes operating and the fluctuating levels of human activity. For example, high risk areas (for low through high activity) for the month of August represent 1.2% of the study area, whereas in September they represent <0.5%. Although these figures represent only a small proportion of the whole study area, they, in conjunction with the spatial distribution of these high risk areas, reflect the nature of the processes occurring and the type of human activity.

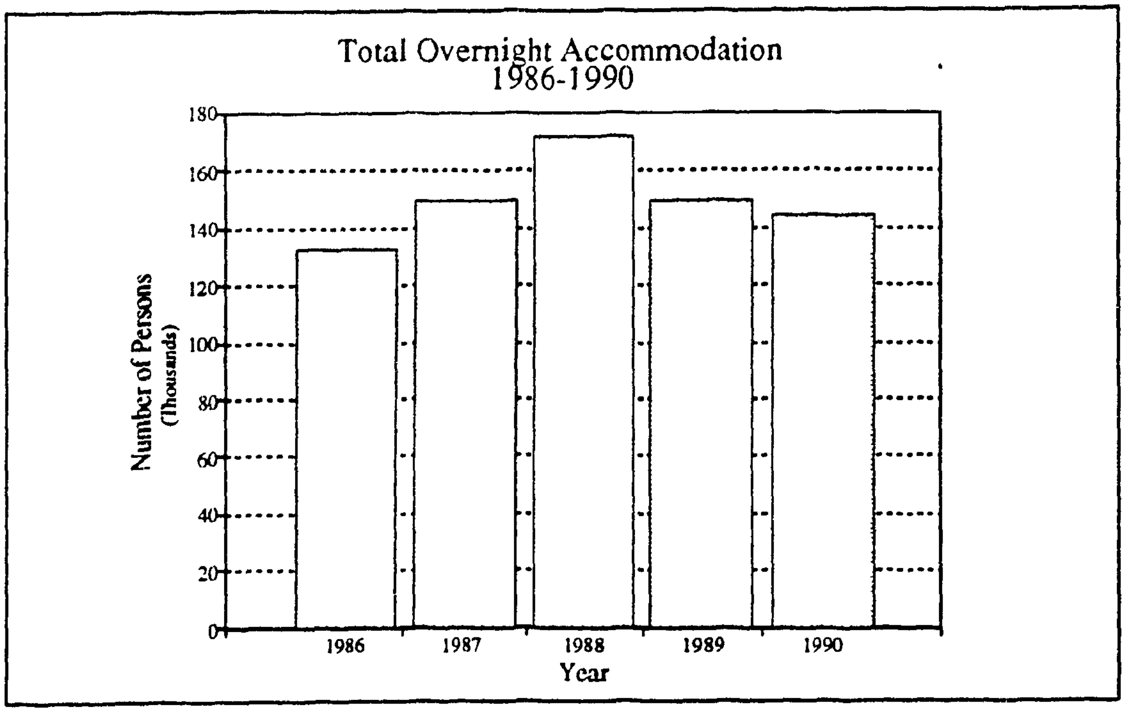


Figure 5.26: Increase in Park Usage 1984-1990

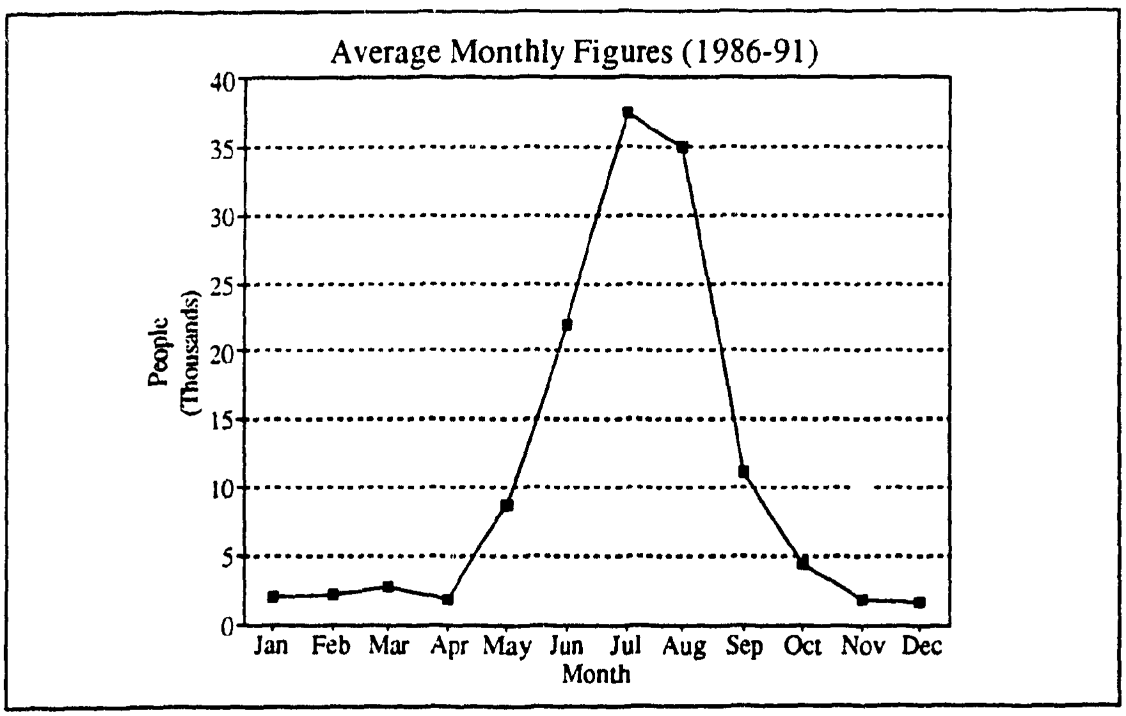


Figure 5.27: Seasonal Use of Park

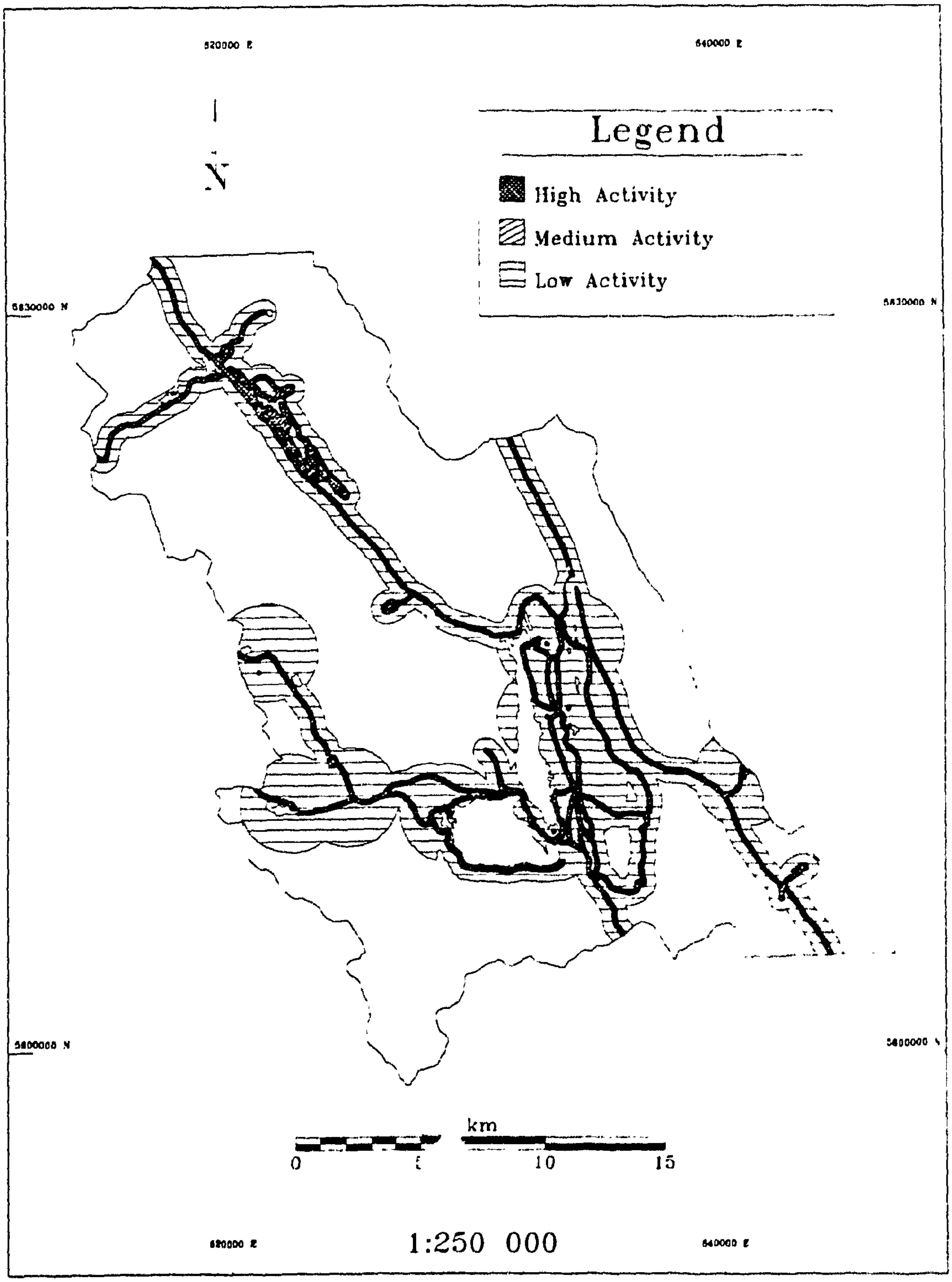


Figure 5.28: Activity Map for August

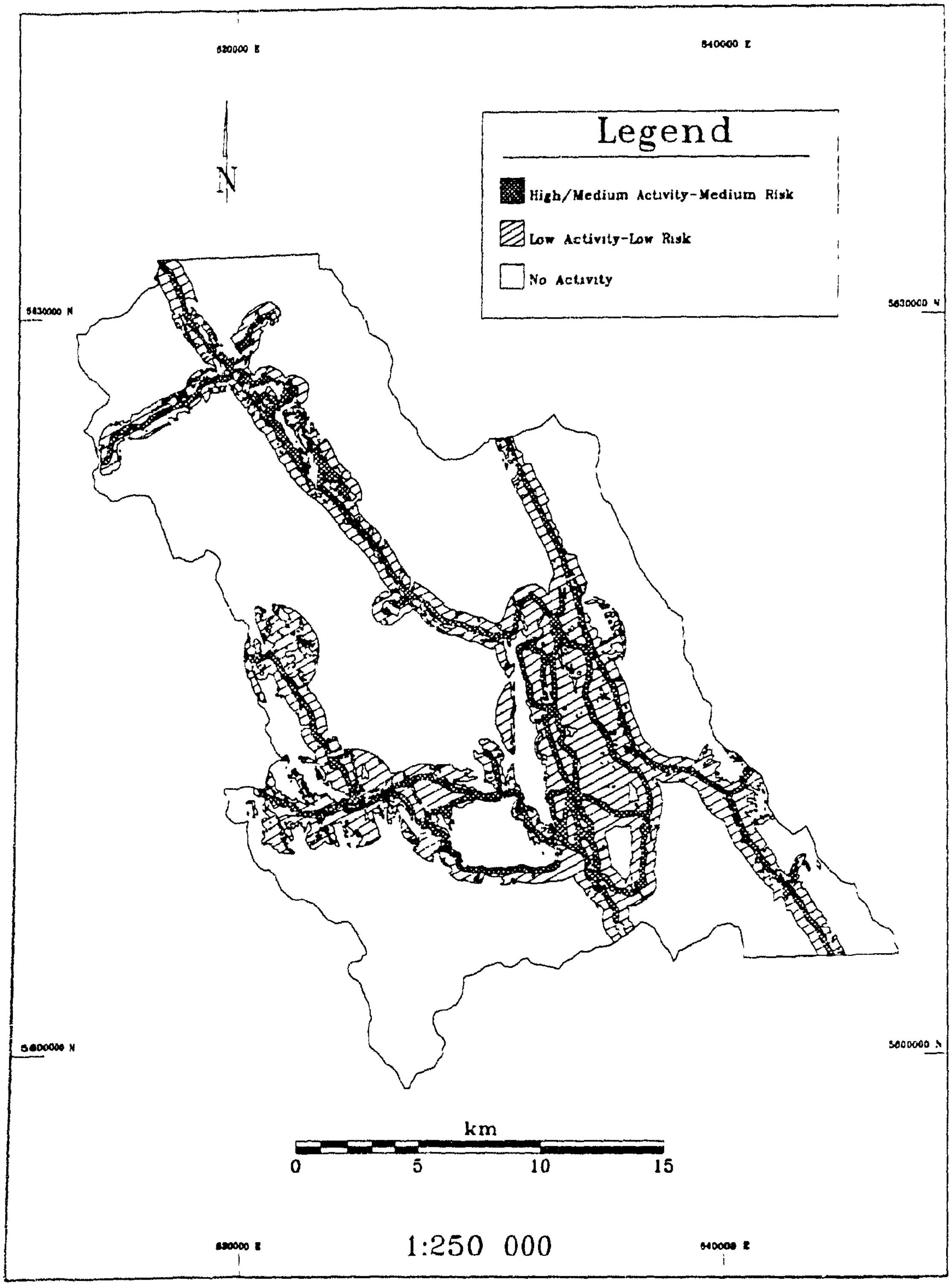


Figure 5.29: Low Activity/Medium Risk Areas (August)

CHAPTER 6

Discussion and Conclusions

The results obtained and the methodology used are discussed in the broad framework of multiple hazard research for land-use planning. What follows is an assessment of the hazard mapping, prediction, and risk estimation, a discussion on the use of geographical information system technology in this field, the practical value of the research with respect to land use management, the limitations of the data and methodology, the conclusions reached, and recommendations for future research of this nature.

6.1 Hazard Mapping

The hazardous processes used in the analysis were chosen, in part to represent the most common hazards in such an environment, and also due to the availability of data relating to them. Ideally, all hazards occurring in the study area would have been analyzed, giving a better representation of the physical processes, but due to logistical reasons this was not possible. This would have included such processes as debris flows, seismic activity, and torrents. The hazards were mapped by identifying the processes from secondary data collected. This involved reclassifying the data to create hazard inventory maps. This method provided satisfactory results for the purpose of this research, but more recent data and more accurate methods could have been employed. Field surveying could have been carried out to provide a more accurate technique of hazard identification. For example, with avalanche hazard, starting zones, tracks, and runout zones could all be identified to give a more meaningful analysis relating to the process. The same is true of rockslide/rockfall hazard, where the mapping methods were limited to identification of debris associated with these events. Forest fire and flood hazard mapping could have benefited from analysis of events over an extended period of time.

6.2 Hazard Prediction and Risk Assessment

With the hazards identified, it was possible to develop a methodology whereby potentially hazardous areas were delineated. This was carried out for each hazard, resulting in susceptibility maps for avalanche, forest fire, rockslide/rockfall, and flood occurrence. It can be seen that the potential for natural hazard occurrence in the study area is fairly significant, despite the generally low rates experienced at present. Fatalities from natural hazards in the park are relatively low, with eight deaths during 1991. Figure 6.1 shows a slight increase, despite fluctuating, in figures representing fatalities for the period 1979-1991.

The prediction procedure involved analyzing each hazard mapped in relation to the other data sources to reveal any associations between the two. The data sets

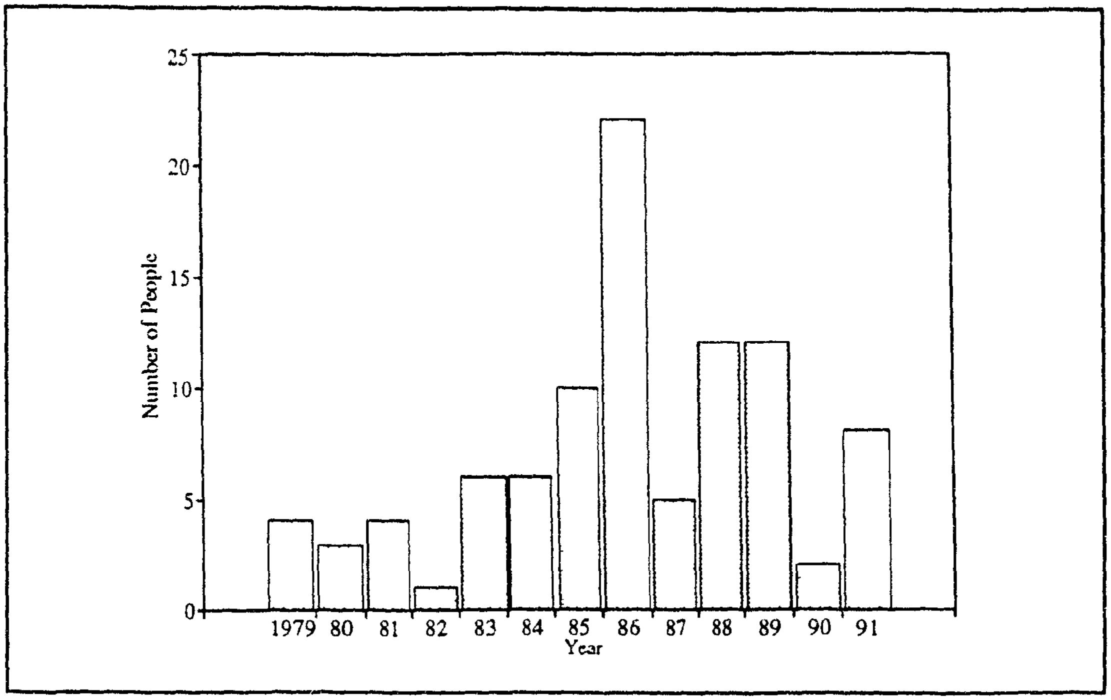


Figure 6.1: Fatalities from natural hazards: 1979-1991 (Source: Alberta Parks and Recreation).

were then weighted and their individual classes ranked in order to perform index overlays to produce susceptibility maps. This represents the fundamental procedure in the prediction process, with the final results determined by these values. The method of determining the weights and ranks could be construed as being the weak point of the analysis, and thus their importance must be stressed. If more accurate or reliable results are required, then a more robust method must be developed for assigning the weights and ranks. For the purpose of this research, they were assigned using value judgements that relied on the results of cross tabulation analysis, in conjunction with knowledge of the processes. Despite the limitations of this approach, it does provide a valuable method of determining hazard susceptibility. Risk estimation was carried out in the same manner, with index overlays used to produce composite maps of potential and actual risk. The weights used for each map were based on their temporal nature, and assigned by analyzing frequency data relating to each hazard. Mapping of human activity involved identifying locations of facilities within the park, in addition to analyzing data related data. These methods could also be considered rather rudimentary, but provide a valuable means of representing the spatial and temporal nature of the human component in the study area. It must be noted that the activity maps can also be modified according to changes in data or other factors not previously considered, providing a flexible approach to the risk estimation. For example, proposed development areas can be incorporated into the data set to give an indication of the physical characteristics of the area, and also the degree of risk from various hazards. This kind of analysis is useful for determining suitability of an area for a particular type of development.

This is achieved by using the point modelling function of SPANS, whereby the area of interest is used to extract the classes or attributes from the maps of interested. That is, the data table for the area of interest has fields appended to it representing the attributes of the various maps. The updated table contains data relating to physical characteristics, such as average elevation, slope, aspect, geology, and also to the hazard susceptibility indices. This procedure may be carried out with point or polygonal data if required, providing an efficient method of determining suitability of an area for development with respect to the hazardous processes identified. Depending on the type of development, the importance of each hazard can be evaluated according to the threat posed by it. For example, avalanche hazard could be considered more of a threat to campsite location than actual structural developments, which can be constructed to withstand the impact of avalanches.

In the case of avalanche hazard susceptibility, the majority of high risk areas occur in the western portion of the park, although there are high risk areas in the vicinity of the Highwood Pass. Analysis of the avalanche hazard in relation to location of roads, trails, and campsites, suggests that danger from avalanche hazard is minimal. Over 96% of the high risk areas occur more than 500m from major roads, 90% more than 500m from trails, and 98% more than 2km from campgrounds and facilities. It was found with fire hazard that most of the high risk areas are located in the lower elevation bands, where the abundance of vegetation is prominent. When analyzed in relation to human activity, the values obtained were found to be more significant than from avalanche hazard. Over 20% of the high risk areas occur within 500m of major roads, over 30% within 500m of trails, and over 25% within 2km of campsites. High rockfall hazard appears to be concentrated in the south westerly areas of the park, on the steep scarp slopes of the Spray Range. Only small proportions of high susceptibility areas occur in close proximity to major roads and trails, but it was noted that about 12% of the high risk areas occur within 2km of campsites. Areas of high flood susceptibility are found to be concentrated around areas of human activity. Over 40% of these areas are within 500m of trails, over 35% within 500m of major roads, and over 30% within 2km of campsites and facilities.

Table 6.1 illustrates the percentage of high risk areas, calculated from the susceptibility maps, that are within the specified distances from roads, trails, and campgrounds.

	Distance from Feature		
Hazard	<500m (Roads)	<500m (Trails)	<1km (Camps)
Avalanche	4%	10%	2%
Forest Fire	20%	30%	25%
Rockfall	<1%	<1%	12%
Flood	35%	40%	30%

Table 6.1: Percentage of High Risk areas in Relation to distance from Roads, Trails, and Campgrounds.

It is apparent from the results that flooding provides the major threat to human activity in the area, despite the fact that the proportion of the total area represented by high susceptibility areas, rank the lowest out of all the hazards. This is a direct result of human activity being at its highest in these areas. High fire hazard ranks highest as a proportion of the whole study area (58%), but when analyzed in conjunction with human activity, areas experiencing high fire hazard and high human activity represent a significantly lower value (3%).

This illustrates the importance of analyzing the human component in the risk estimation process, which represents a significant element in multiple hazard research. The potential and actual risk experienced from multiple or single hazards may vary greatly, illustrated with the case of fire hazard. Since these results may vary greatly, close attention must be paid to the methods used in the different risk estimation procedures if dependable results are required.

6.3 Application of GIS to Multiple Hazard Research

Geographic Information Systems have become one of the most powerful tools for use in environmental applications. The ability to analyze, manipulate, and spatially relate various forms of geographic data under a common framework, provides for efficient and effective analysis on which to base decisions. The use of GIS in hazard research is becoming more apparent, with an increasing number of research projects adopting such techniques. The advantages and disadvantages of using such techniques, as established from this research, are discussed.

Probably the most important advantage of using a GIS in any research is that it provides a common framework for all data to be stored and manipulated under, regardless of scale, structure, or source. Multiple hazard research requires large amounts of disparate data to be collected, relating to the physical characteristics and the human activity in the area. These data are generally in a variety of formats, which can lead to problems when analyzed by conventional methods. For example, the lack of ability to correlate certain characteristics with each other, or to overlay data sets. Thus, the GIS allows all the data to be stored and represented under the same geographical reference and at the same scale. Maps of different scales can be digitally input to the system and analyzed in conjunction with each other, eliminating the problems of compatibility experienced with conventional methods. The analysis performed using a GIS provides quantitative data on physical characteristics that would otherwise be hard or extremely time consuming to obtain. For example, slope and aspect maps are easily derived from the elevation data, providing new data sets from the original input data.

The most significant feature of the GIS for hazard research is the ability to predict potentially hazardous areas based on user selected criteria. Index overlays provide the means of obtaining such results. The criteria used in this procedure can be determined from cross tabulation results, which provides a method of investigating any correlations between hazardous processes and physical characteristics. These criteria may be altered at any time to reflect incorporation of new data, or to recognize changing variables. 'What if...' questions may be defined by the user to show the impact of various physical or human process on the assessment procedure. For example, if vegetative cover were removed in certain areas, what would be the potential for an increase in hazard susceptibility. Assuming the criteria used in the prediction procedures are accurate, quantitative data relating to hazardous processes and their associated risk can be obtained.

The output of results can be obtained in a variety of formats, depending on their purpose. Hardcopy maps can be printed via postscript printer, tabular results can be graphed or stored in spreadsheets for further analysis, and data can be output in various digital formats for use with other applications. This recognizes the problem of data availability and compatibility between systems, allowing the data to be utilized for a variety of purposes. Output of results is also available through the graphical user interface (GUI) of the GIS, allowing selective, on-line retrieval and manipulation of data. A major advantage is the ease of use of such interfaces, which are generally mouse driven and have on-line help facilities. The GUI can be tailored to provide functions of interest to non specialist users, in order for them to obtain information efficiently. In general, output can be obtained in a variety of formats to suit a variety of purposes.

The equipment used in this research can be considered relatively inexpensive (at time of writing) and within the budget of most serious research organizations. Equipment such as this can be as effective as la e expensive systems, especially for the purpose of data analysis for hazards management. Larger systems tend to be more difficult to maintain and require more technical skills, which in the case of hazard research, may not be worth the extra costs involved.

The disadvantages of using GIS technology in hazard research, or any kind of research for that matter, is the 'black box' scenario. That is, using a system such as this without understanding the processes occurring. The potential to draw conclusions from the results without an understanding of the fundamental concepts of the analysis is ever present. It must be stressed that users of such a system be aware of this potential problem, and justify any conclusions with respect to the analysis performed. If this type of information is to be utilized by land use planners, they must understand the logic behind how the results are obtained, or decisions could be made based on wrong assumptions.

Other problems encountered were the time consuming input of data into the system, the long processing times necessary for performing analysis and output of results, and storage requirements. For example, to prepare maps for final output to the postscript printer, times in excess of ten hours were to be expected. These procedures can be run in batch mode therefore not requiring continual operator supervision, but this could be a major problem if using a mainframe system where you may be charged directly for CPU[7] time, thus increasing the cost of such analysis considerably. Storage requirements can also be of major concern, especially when working on PC's, with the 200 megabyte hard disk used for this research almost at capacity from the software and data.

6.4 Research as a Land Use Management Tool

The question must be asked, how effective is the research when applied to

[7] Central Processing Unit, controlling computer system

land use planning and management in the area? What can be achieved from this research that otherwise would not have been achieved? The answer lies in the importance of policies implicated by decision makers. Hazard research provides information to inform policy makers of potentially hazardous situations. Hestnes and Lied (1980) suggest that in land use planning, it would be unrealistic to guarantee 100% safety against hazards, especially in a mountain environment, but it is possible to efficiently manage the land use in an area to benefit both society and nature.

The preparation of hazard susceptibility and risk maps provides quantitative data for the policy makers to base decisions upon, providing they have a clear understanding of how the results were obtained. It is suggested that the results from this kind of research be used to achieve proper communication between the researcher and the policy makers. A major goal is the ability to work with the land use planners to provide the optimum policies in the study area, in addition to alerting the public to the fact that a considerable, if not precisely determined, degree of risk from natural hazards exists. It must be noted, though, that how safe an area should be for any particular use is a political question. The role of the hazard researcher is limited to quantifying as accurately as possible, the spatial and temporal nature of risk in the area.

6.5 Limitations of Research

The limitations of the research will be discussed with respect to data sources, input, analysis, and output. Regarding the original data sources, only limited data was used to represent hazardous processes occurring. Other processes could have been taken into consideration to provide a more comprehensive analysis, in addition to better data relating to frequency of occurrence. The accuracy and age of the data varied, from digital format stream discharge data to generalized maps of vegetation. It is difficult to quantify the errors associated with the original data sources without having knowledge of how the data was derived. Data was stored at a grid resolution of 12 metres, which exceeded the tolerance of the digitizer used.

The most obvious limitations associated with the research involve the analysis procedures, primarily the criteria used in the prediction and risk estimation of the hazards. The criteria used to predict various hazards were based on analysis of known occurrences of the processes and previous research results from related studies. Attempts were made to quantify as accurately as possible the various factors involved in their occurrence, and use these results to predict areas potentially susceptible to the hazard. Despite this, susceptibility ratings were based on a high, medium, low scale for lack of a better scheme. It is suggested that these ranks could be modified to give a more accurate representation of susceptibility ratings and also in the risk estimation process. This could be achieved by using more classifications to represent susceptibility, for example on a scale of 1 to 100, which would provide more comprehensive results. What the system does provide, however, is a method by which these criteria can be changed to reflect different conditions specified by the user.

Representation of the human activity in the park could also have been improved on. Data relating to campsite and trail usage was not broken down by individual locations, which would have provided a more realistic portrayal for use in the analysis. Combined with the same problems inherent in production of the susceptibility maps, the risk estimation process suffers severe limitations. The shortcomings of the index overlays are amplified by repeating the process with data already produced by that method. The maps produced as output were generalized for presentation purposes, and thus did not take full advantage of the benefits of the GIS. If larger sized maps had been produced, more data could have been included to enhance the final results.

6.6 Concluding Remarks

The objectives of this study were to identify hazardous and potentially hazardous areas and estimate their degree of risk, and to assess the application of GIS techniques to multiple hazard research. These objectives were met, despite various limitations associated with the results.

A representative selection of hazardous processes were used in the analysis, in order to map these processes and associate any contributing factors to their occurrence. Susceptibility maps were produced for each hazard (avalanche, forest fire, rockfall/slide, and flood) to illustrate the spatial distribution of each particular process. Based on the prediction criteria, it was found that the largest proportion of high susceptibility areas occur from forest fire hazard. This risk was then associated with the human activity in the area, and the relative risk from each hazard calculated. It was found that, for the month of August, flood hazard represents the major threat to human activity in the area.

Assessment of the application of GIS techniques to multiple hazards research suggests that it provides an effective and flexible approach to mapping and predicting hazardous processes, with the many advantages encountered out-weighing the disadvantages. The technology and methodology used enables analysis to be carried out that would be either impossible, extremely time consuming, or costly by conventional methods. Information can be obtained effectively from the system, and modelling scenarios can be performed to assess the importance of certain variables in the hazard prediction process. Due to the flexibility of the system, it is suggested that it could be applied to other study sites to perform similar analysis. In addition, the use of PC technology was found to be adequate for the task, as opposed to mainframe systems. There are trade-offs for using both types of system, therefore the decision as to which type of system and what equipment should be used is something that has to be established with relation to the size and scope of each individual study.

It could be argued that the data and methods used in the analysis, are in fact more valuable than highly specific data relating to slope mechanics, for example. The final results representing spatial and temporal patterns of hazards and risk, could not have been achieved without the integration and analytical functions of GIS. Although the methods have their limitations, they allow for an effective analysis of the data provided.

The significance of the results are realized when applied to land use planning and management procedures. Decisions can be made based on the information provided by such research, in order to efficiently manage the land use in the park. This research quantifies the risk occurring, allowing the results to be more interpretable to the policy makers. It is suggested that the users of such information have knowledge of the procedures involved in calculating the results, either by direct involvement with the project, or by close communication with the researchers.

6.7 Recommendations for Future Research

From the analysis of the limitations of the research, a number of improvements are suggested in order to enhance the validity of results. These are discussed to provide recommendations for future work of this nature.

Data collection should be as thorough as possible, covering all hazards occurring in the area, in addition to more comprehensive data on the frequency calculations. Other variables should also be taken into consideration, for example, climatological data, and more comprehensive data relating to human activity. Conversion of data to digital format is a time consuming, labour intensive process, something that could be automated with the aid of digital scanners, and subsequently lead to more quantitative error calculations. The susceptibility ratings could be improved to represent more degrees of risk instead of just the high, medium, and low ratings used. This would provide a more practical representation of potentially hazardous areas in the park. Finally, faster and more powerful computer equipment would decrease processing times significantly, but is not deemed essential for a project of this size and scope. Most projects of this nature probably make use of available technology, but in the case of a research project being implemented it is recommended that equipment be purchased depending on the objectives, scope and size of the project.

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