THE MEASUREMENT OF THE NATURAL POTENTIAL OF SITES IN THE EASTERN HIGHLANDS OF SCOTLAND FOR DOWNHILL SKIING

by

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DECLARATION

In accordance with the University of Edinburgh postgraduate study regulation 2.4.15, the following declaration is made by me:

This study was composed by me and is based on my own research and has not been submitted for any other degree.

Richard W. Davison

July, 1985.

ABSTRACT

The aim of the thesis is to measure the natural potential of sites in the Eastern Highlands of Scotland for downhill skiing accurately. Natural potential is defined as consistent snowcover during the winter. Measurement is based on the influence of the morphology of the land surface on the supply, entrapment and retention of snow. Five processes that control the consistency of snowcover were identified: the creation of air turbulence, gradients of precipitation and temperature, global radiation, the upwind depletion of snow and the relative supply of snow. It was hypothesised that the site with the most consistent snowcover would have the best combination of values on the variables identified to represent these processes.

To provide data on the relative supply of snow, the geostrophic wind speed and direction and the type of precipitation were measured for the study area for 4538 days in the winters 1954/5 to 1983/4. The results challenge many long-held beliefs of skiers and researchers. The geostrophic wind was found to be an adequate indicator of surface wind speeds on the summits of mountains.

Eleven variables representing the five processes were measured for 54 sites drawn at random from the Cairngorm Mountains and the SE Grampian Highlands. Principal components analysis was used to identify those relationships that indicated consistent snowcover at sites. The component scores accounted for up to 88% of the variation in the extent of snowcover as measured from aerial photographs and Landsat scenes. Results were highest for dates on which the period of melt was well advanced. The component scores, therefore, are valid measures of natural potential and the results challenge the opinions and statements of many skiers and planners.

Groups of sites with similar natural potential were identified using cluster analysis and the results were tested using discriminant analysis. Three functions classified 46 of the 54 sites correctly. The functions, and regression equations developed to predict scores on the components, can be used to analyse the remaining sites within the study area.

Research in future could measure regional patterns of precipitation, improve the definition of the variables and measure wind speed and direction at individual sites. The method could be applied to other land uses and to a definition of potential that includes access to sites and the conservation of nature and landscape.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND AND AIMS

The original intention of this research was to assess the potential of upland areas for outdoor recreation and, in particular, to move towards its accurate measurement. The need for accurate measurement was identified from earlier work (Davison, 1981, 1982a) which suggested that measurement is based usually on implicit assumptions which are rarely tested and that when such tests are made the results are often different.

Although many types of outdoor recreation are possible in upland areas (e.g., climbing, downhill skiing, pony trekking, rambling, shooting), it was necessary to concentrate on only one of these owing to constraints of time. Downhill skiing was chosen for three main reasons.

1. Downhill skiing is an important activity in upland areas (and in particular the Scottish Highlands), providing employment in many rural communities (Getz, 1980).
2. It is a very site-specific activity, unlike rambling, for example, which occurs on a fairly random basis throughout the Highlands.
3. The development of facilities for downhill skiing involves the provision of infrastructure in the form of road access, water, electricity, accommodation and facilities for use in wet weather. This infrastructure usually requires expenditure by local and national authorities and is an important issue, therefore, in areas such as the Scottish Highlands. It is important, therefore,

that the siting of new facilities is based on the accurate measurement of the potential of each site.

Potential is generally equated with the suitability of land for a specific land use (Dent and Young, 1981) and usually involves the classification of land (Canada Land Inventory, 1969; Davidson, 1980), with each class representing a certain level of potential. Although Davison (1981) equated potential with the physical, social, economic and environmental aspects of land use, this research uses a more concise definition of potential for two reasons.

First, there was a need to concentrate on a single aspect of potential where the relationships between the land use and the land being evaluated are known so that it could be measured and validated accurately. Research in Switzerland and Austria (reviewed by Watson and Watson (1984) and Davison (1985); Messerli, pers. comm.) suggests that knowledge of the inter-relationships between the physical, economic, environmental and social aspects of development is limited and site-specific. The identification of a dependent variable to represent potential for use in validating the results is likely, therefore, to be difficult and time-consuming (and hence inappropriate for a PhD thesis to be completed within three years).

Second, when a large number of sites are to be studied, there is a tendency for social and economic factors to become less important in discriminating between individual sites. Coire Cas and Coire na Ciste (both at Cairn Gorm), for example, would have similar social and economic impacts because they affect the same communities, whereas Aonach Mor and Ben Wyvis would not because they affect different communities. Figure 1.1 shows the location of the existing ski areas and those sites for which development has been proposed or considered.

To some extent, social and economic impact is dependent upon the size of the development and on the physical characteristics of the site (Messerli, 1983; Davison, 1985). The basic physical requirements for downhill skiing are consistent snowcover during the winter (December to April inclusive) and slopes of suitable angle and length. The suitability of the latter can be determined only by examining the design and siting of facilities and ski runs in relation to the terrain (Branch, pers. comm.). When a large number of sites are to be studied this is clearly not feasible. The research, therefore, is concerned with the measurement of natural potential, which is defined as consistent snowcover during the winter. A dependent variable should be identified more easily to represent the consistency of snowcover than for a wider definition of potential.

The snow and weather conditions in Scotland have been described as marginal for downhill skiing by Perry (1971), Smith (1975) and many others. It is surprising, therefore, that snow and weather conditions have been largely ignored by planners and decision-makers (McVean and Lockie, 1969; Scottish Development Department, 1984) and that little is known of conditions at any site within Scotland, including the existing ski areas and sites

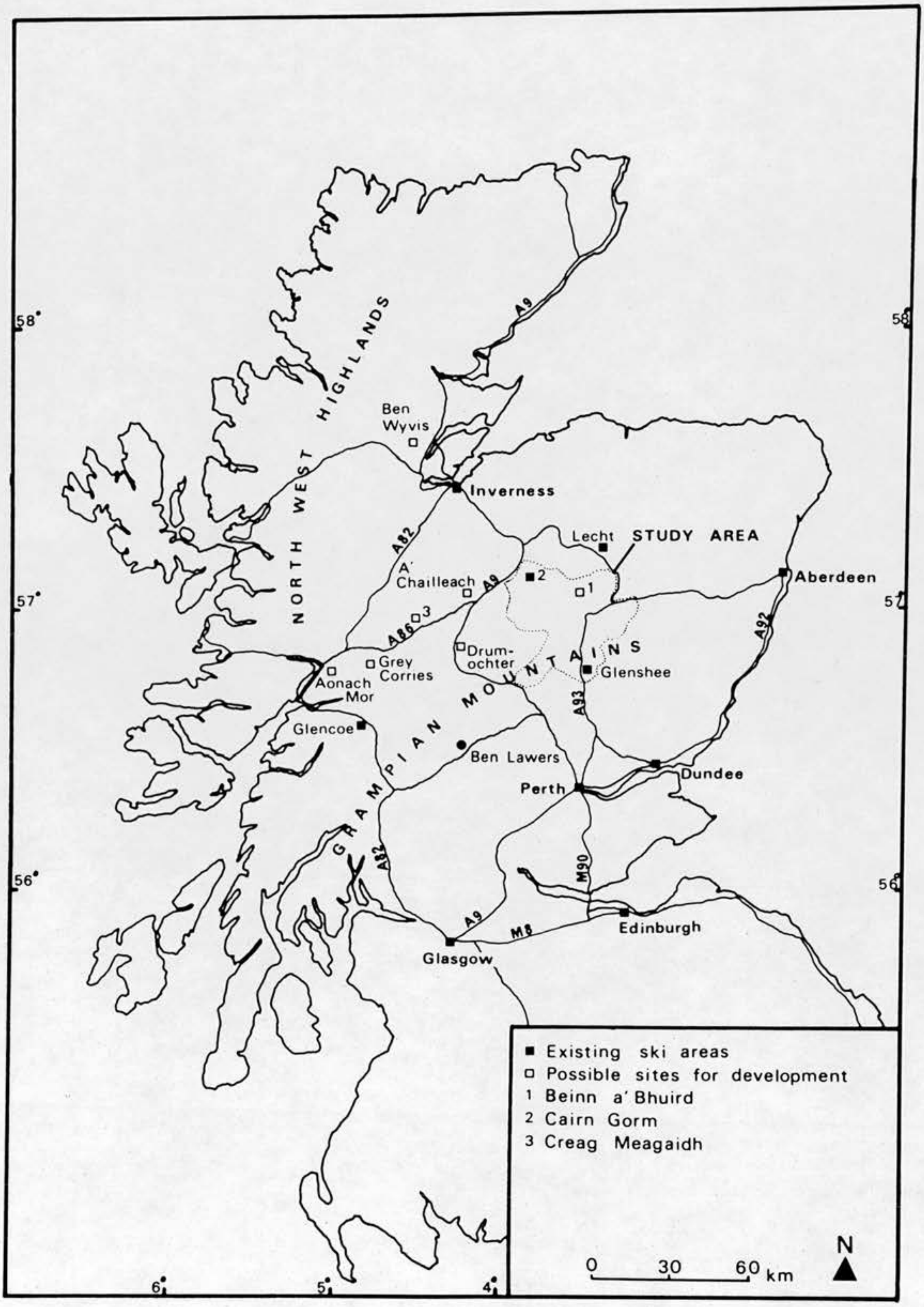


Figure1.1: Map showing the location of existing and possible ski areas in Scotland.

where feasibility studies have been undertaken (see Figure 1.1). There has also been disagreement over the number of sites with potential for downhill skiing; the Langmuir Ski Group (1979), for example, suggested that the list of sites was far from complete, while Baker and Gordon (1980) concluded that there was agreement on a list of worth-while alternatives for development. A study of the natural potential of sites is likely to be of relevance, therefore, to planners and decision-makers.

The aim of this research, therefore, is to measure the natural potential of sites for downhill skiing. More specifically, the research has five objectives:

1. to identify those processes that control the consistency of snowcover at a site;
2. to develop a method that can be used to measure the natural potential of sites for downhill skiing accurately;
3. to validate the results using data on the consistency of snowcover;
4. to improve knowledge of the processes that control the consistency of snowcover; and
5. to suggest ways in which the knowledge gained can be used to refine the method.

1.2 DEFINITIONS

A site with natural potential for downhill skiing was defined in the previous section as having consistent snowcover during the winter (December to April inclusive). The consistency of snowcover is used as an all-embracing term which covers the duration and depth of snowcover at a site, such that the site with the most consistent snowcover is likely to have the deepest and longest-lasting snowcover of any site. As the research is concerned with the potential of a site prior to development, the possible benefits arising from the use of snowfencing (to induce the drifting of snow), the use of equipment to make snow artificially and the modification of slopes to induce drifting (Hünerwadel et al., 1981) are not studied.

A site is taken to be any drainage basin and its principal stream which meet the following requirements:

1. it must have a bottom altitude of below 750m;
2. the source of the stream must be above 800m, and
3. the relief between (1) and (2) must be greater than 200m.

A lower limit of 600m for any site was applied, largely because the existing ski areas all have a bottom altitude of approximately 600m. Although these requirements would exclude two existing ski areas (Glenshee and the Lecht) from the total population of sites (none of the streams at these sites meet the requirements), it was thought necessary to have sites that had specific locations and that could be identified easily from OS maps. It is assumed by many that substantial deposits of snow can build up within gullies where it lasts longer than elsewhere within the basin. A gully is defined as the stream and the channel which it occupies.

The study area is the Eastern Highlands of Scotland, which includes the Cairngorm Mountains and the Grampian Highlands between Beinn a' Ghlo in the west to Lochnagar in the east. Figure 1.2 shows the boundary of the study area. This area was chosen because the network of weather stations is better than for any other part of the Scottish Highlands; the terrain is relatively consistent throughout the area; and most of the research that has been concerned with snow conditions has been undertaken within the area.

When the requirements listed above were applied to the study area, 180 sites were identified. Owing to constraints of time, a sample of 54 sites was taken at random from this total; the names of these 54 sites are listed in Appendix One and their locations shown on the two maps in that Appendix. For the purpose of validating the results, it is necessary that the sample be drawn at random from a population that includes all sites within the study area. Sites with the least, and those with the most, consistent snowcover can then be studied. The population and sample of sites pays no attention, therefore, to areas of nature conservation or to access. It is left to other researchers or organisations to "screen" the sites for accessibility, or for influence on the conservation of nature and landscape, once the consistency of snowcover at each has been established.

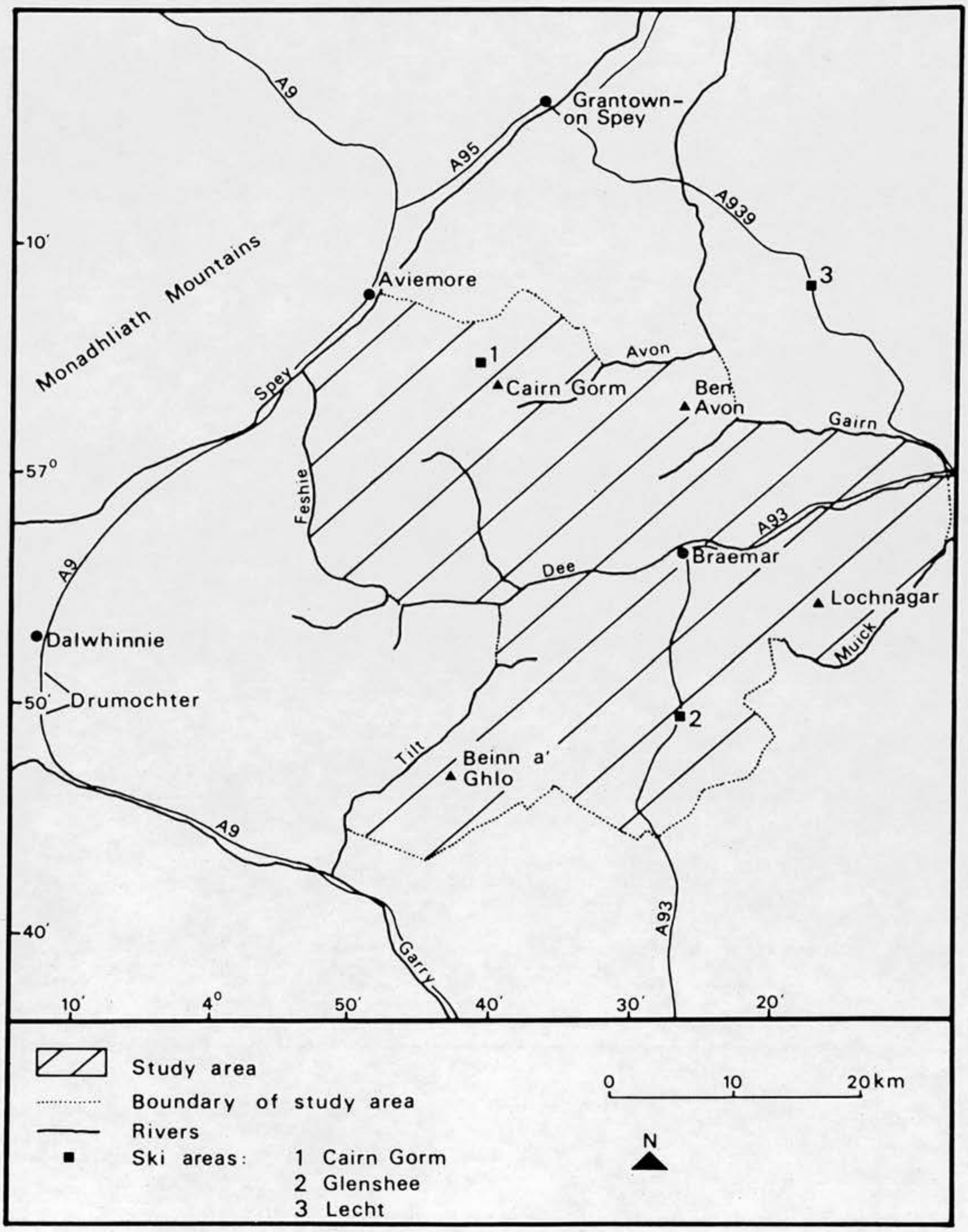


Figure 1.2: Location of the boundary of the study area.

1.3 STRUCTURE OF THE THESIS

The thesis is divided into five parts. The first establishes the importance of the consistency of snowcover on the siting and operation of facilities for downhill skiing and reviews the incorporation of data on the consistency of snowcover in planning for the development of facilities in Scotland, North America and Switzerland. The section also examines the sources of data on the consistency of snowcover. The second identifies the processes that control the consistency of snowcover at a site, and identifies variables to represent them. A method that can be used to measure natural potential accurately is described in detail. This section also develops a verifiable and objective database on winter weather over the period 1954/5 to 1983/4 that is used to provide data on the supply of snow to each site.

The third section uses the method outlined in the second section to measure the natural potential of sites accurately. The fourth section validates and verifies the results using data that represents the consistency of snowcover. The section also examines the method and its results critically. The final section presents two case studies to illustrate the possible applications of the method.

CHAPTER 2: THE CONSISTENCY OF SNOWCOVER AND THE DEVELOPMENT AND OPERATION OF FACILITIES FOR DOWNHILL SKIING

2.1 INTRODUCTION

In Chapter One, it was noted that the snow and weather conditions in the Scottish Highlands are considered to be marginal for downhill skiing by Perry (1971), Smith (1975) and many others. With the proposals to develop facilities for downhill skiing at Aonach Mor, Ben Wyvis and Drumochter, it is important that the natural potential of sites is measured accurately. This chapter reviews both the influence of the consistency of snowcover on the development and operation of facilities for downhill skiing and the sources of data on the consistency of snowcover. A procedure will be identified for use in meeting the objectives of this thesis.

Reference is made throughout the chapter to the procedures adopted in Switzerland and in North America, as well as those in the Scottish Highlands.

2.2 THE INFLUENCE OF SNOWCOVER ON THE DEVELOPMENT AND OPERATION OF FACILITIES FOR DOWNHILL SKIING

2.2.1 Background

In Switzerland, one third of all ski areas make adequate profits, one third break even and the remaining third produce no profits at all, with the main problem being that of cashflow (Schmid, pers. comm.). Schaer (1976, p.181) analysed the operation of cable cars in Switzerland and noted that increases in the cost of borrowing money were not being met by an increased volume of passengers and revenue, and concluded that this was "...a vicious circle from which various loss-making cable-car businesses will now hardly be able to escape".

A similar situation is evident in North America, where financial data on the skiing industry are more widely available. Table 2.1 shows the percentage of ski areas reporting profits or

Table 2.1: Ski areas in North America reporting profits or losses (from Goeldner and Farwell, 1980).

	1979/80		1978/9	1977/8	1976/7	1975/6
Dollars (000)	Number	%	%	%	%	%
Loss	55	42.0	26.6	12.3	48.0	26.1
Profit:						
0 - 24.9	6	4.6	9.7	5.2	8.7	13.0
25 - 49.9	7	5.3	7.3	8.8	3.9	13.9
50 - 99.9	9	6.9	8.9	14.1	10.2	14.8
100 - 149.9	12	9.2	3.2	8.7	6.3	6.1
150 - 249.9	7	5.3	9.7	10.5	10.2	6.1
250 - 349.9	3	2.3	5.6	7.9	3.9	6.1
350 - 999.9	15	11.5	17.7	22.9	6.3	8.7
1000 - 1999.9	10	7.6	5.6	7.0	1.6	2.6
2000+	7	5.3	5.6	2.6	0.8	2.6

losses during five winters from 1975/6 to 1979/80. The percentage making losses fluctuates from winter to winter, with a mean value of 31%. The seasons of 1976/7 and 1979/80 had poor snowcover (Wilson, 1981) and a high percentage of areas reporting losses. Goeldner and Farwell (1980, p.4) noted that these figures do not include all ski areas, so non-respondents "...could be weighted heavily by loss operations or by small operators who do not have a great interest in the study". The actual percentage of ski areas making losses, therefore, is probably higher than the total in Table 2.1.

Leuschner (1970) reported that ski areas in the United States around the Great Lakes were "relatively unprofitable". Smith

(1974, p.58) found that only 35 ski areas out of a total of 136 were financially successful in the U.S.A. over the period 1964 to 1968 and concluded that "...climatic risks may be a leading cause of bankruptcy after several poor seasons". Nelson (1971, p.105) noted that many facilities for downhill skiing had been located without any detailed analysis of climate, and suggested that "...sites were selected by local people familiar with long-term snow and weather conditions, and who felt, therefore, no need to take lengthy and expensive climatic measurements". Nelson concluded that "...a lack of dependable snow is a factor in the decline of former ski sites and helps explain why others have remained in a purely local status" (p. 119).

Farnes (1971) drew a map showing those areas in SW Montana where depths of snow are favourable to downhill skiing and found that all closed or abandoned sites were located outside of these areas. Price (1970) concluded that less than 50% of 500 ski areas in North America made profits consistently. Most resorts in the Rocky Mountains in Canada "...reported widespread losses in years with poor snow conditions, and inadequate returns on investment even in good ones" (Sandor, 1980; p. 337).

In Scotland, as in Switzerland and North America, sites which were perceived to have potential for development were identified by local people and skiers. No detailed measurements of snow and weather conditions were undertaken. Development on a small scale initially occurred at Beinn Ghlas (Ben Lawers), Ben Gulabin, Carn an Tuirc and Creag Bhealg in the 1930s to 1950s (see Location Maps in Appendix One), but all four areas failed owing to unreliable snowcover (the 1930s are regarded as particularly poor for snow by Green, 1973). Creag Bhealg (near Braemar) was developed in 1963 and comprised ski lifts, accommodation, car parks and equipment for making artificial snow. This development failed after the winter of 1963/4 because of poor snowcover (see Appendix 4) and the inability to make snow artificially owing to a shortage of suitable weather (Simpson, 1983).

Table 2.2, shows the ski areas divided into two profit-making classes and a loss-making class. The most notable difference

Table 2.2: Characteristics of profitable and loss-making ski areas in North America (from Goeldner and Farwell, 1980; p.39).

	Top-half profits		Bottom-half profits		Loss	
	Mean	Index	Mean	Index	Mean	Index
Length of season (days)	135	1.20	119	1.05	73	0.65
Average utilisation (%)	55.9	1.17	39.6	0.83	33.3	0.70
Operating profit ('000$)	1282	2.53	182	0.36	(151)	-
Return on GFA (%)	22.9	1.89	5.2	0.43	Loss	-
Revenue/skier visit	11.30	1.03	10.09	0.92	10.41	0.95
Size (VTF/hour) ('000)	6730	1.35	4388	0.88	3248	0.65

GFA Gross fixed assets
VTF Vertcal transport feet

between the three classes is the length of season, which appears to be related closely to the operating profit and the return on gross fixed assets. If the length of the season is short (i.e., the snowcover is inconsistent), the operating profit is likely to be low or non-existent.

2.2.2 Review of the probable causes of the financial problems confronting skiing areas

In the last section it was suggested that a link may exist between the financial problems confronting many ski areas in the

Switzerland and in North America and the consistency of snowcover at these areas. The length of the season has perhaps the most direct influence on the financial success or failure of ski areas (Martinelli, 1976).

The revenue for any ski area can be predicted by multiplying the number of skiers who visit the area by the revenue raised from each visit. The number of visits is a product of the uplift capacity multiplied by the rate of utilisation and the length of the season (for a full description see Chapter 5 in Davison, 1982b). The capacity of ski areas in Table 2.2 is measured in vertical transport feet per hour which is roughly equivalent to capacities of 5000, 3500 and 2500 skiers per day for the three classes of area (Smith, 1974). For the top-half profit class in Table 2.3, revenue is equivalent to the capacity (5000 skiers) multiplied by the rate of utilisation (55.9%) by the length of

Table 2.3: Influence of the length of season on revenue.

	Revenue 1979/80	Revenue (73 days)
Loss-making	$633,000	$633,000
Bottom-half profit	$1,664,000	$1,020,000
Top-half profit	$4,264,000	$2,306,000

the season (135 days) by the revenue per visit ($11.30). This gives a value of $4,264,000 for 1979/80.

For the lengths of season listed in Table 2.2, there is a wide discrepancy in revenue between the three classes. However, if the length of season was 73 days for all ski areas, differences are much less. Although hypothetical, the results in Table 2.3 show that the extra 62 days in operation at the top-half profit-making areas increases revenue by $2 million. In any one season, revenue could be higher than the figures in Table 2.3 if all weekends and holiday periods (e.g., Christmas, the New Year, Easter) had good snowcover, or lower if conditions were poor. Without the long season, the large resorts could not finance their debt. The availability of a long season has encouraged the construction of hotels near the resorts, thereby increasing the number of skiers who visit the area and hence the ability of the area to make profits.

This argument is confirmed by Goeldner and Farwell (1980), who compared data at the regional level. New England and the Midwest recorded average losses for 1979/80, while the most profitable regions were the Rocky Mountains, California and Nevada. The latter three regions have the largest ski areas, the highest rates of utilisation and the longest seasons. New England and the Mid-West are often subjected to mid-season thaws and so snowcover is less consistent.

A further constraint on the length of the season is the frequency of weather which can close facilities. Such weather includes strong winds, fog, icy slopes and risk from avalanches. Facilities are closed during strong winds for reasons of safety. Strong winds can also erode snow from exposed slopes and thus limit the area available for skiing (Martinelli, 1976; Owens and Prowse, 1979). These factors can further reduce the length of the season and so limit the financial success of ski areas.

Although climate and snowcover are more favourable for downhill skiing in the European Alps and in North America than in Scotland, the four ski areas in Scotland do make profits in many years and these are sufficient enough to finance the development of new facilities. Lord Leven, giving evidence at a public inquiry into proposals to develop facilities for downhill skiing near Cairn Gorm (Scottish Development Department, 1983; p.15), stated that "...the company does not borrow on the money market and so development programmes are largely governed by cash flow and grants from public funds". This raises the question as to why, although conditions are more favourable, many ski areas in the Switzerland and in North America do not make profits.

It was suggested earlier that regional differences in the consistency of snowcover may account for this. In Switzerland, however, the ski areas are all located in close proximity to the major centres of population and to international airports (Bern and Zurich, for example, are closer to the main ski areas in Switzerland than are Edinburgh and Glasgow to the ski areas in Scotland). Those areas with the most consistent snowcover (largely owing to their having slopes of different aspects; see Chapter 3), therefore, tend to dominate the market, so areas with less consistent snowcover (relative to these areas) have financial problems. Potential, therefore, can be relative: although a small resort in Switzerland may have more consistent snowcover than any site in Scotland, it may compare less favourably with other ski areas within Switzerland. The measurement of potential as a relative phenomenon implies that any method should determine if one site is better than another, rather than their actual level of potential, which is a meaningless value if there are no other sites or no standard of potential to compare it with.

The consistency of snowcover and the absence of any detailed surveys of it, however, are not the only causes of the financial problems facing many ski areas. Watson and Watson (1984) noted two further causes. First, rapid changes in the attitudes of skiers. Demand for broad, smooth, fast pistes in the early 1970s, for example, meant that slopes had to be modified, often at great cost. In the mid-1970s, demand changed to pistes that were more testing, off-piste skiing and cross-country skiing and as this required fewer uplift facilities revenue fell, only a few years after the costly expansion of facilities in the early 1970s. Only those ski areas with a sound financial base could withstand the shortfall in revenue.

Second, where a single developer or company owns both the uplift facilities and the accommodation, profits can be supplemented by tourism in summer when few uplift facilities are in use. Package-holidays can also be provided which increases the rate of utilisation in mid-week. The importance to a developer of being able to collect revenue during the summer was noted by Price (1971, p.1) who suggested that "...if there is anything previous failures have pointed up, it is that winter use, no matter how extensive, rarely by itself yields a profit".

The main requirement of any winter resort, however, is consistent snowcover throughout the winter. The more consistent that snowcover is compared to that at neighbouring resorts the more likely that that resort will yield a profit. In Scotland, where the resources are much less favourable, the consistency of snowcover is of paramount importance (Clyde, pers. comm.;

Paterson, pers. comm.; Travis, 1974; North East Mountain Trust, 1983).

2.3 PRESENT PERCEPTION OF THE PROBLEM

In Switzerland, until the mid-1970s, there were few controls on the development and operation of facilities. The growing scale of the financial problems facing many ski areas, however, prompted the Federal Government of Switzerland to increase its control over the development and operation of cable cars and chairlifts, and for the Cantons over the development of skilifts.

The basis for this increased Federal control was the "Konzessionskonzept" (Scmid and Keller, 1977), which stated that detailed costings and plans must be submitted with any proposal to develop new facilities, together with data on the duration of snowcover, the depth of snow and the amount of snowfall, risks from avalanches, the area and capacity of the snowfields and the quality of the pistes. The Federal Government can seek comments from neighbouring competitors (it may refuse permission if there is a danger of other companies being put at greater risk) and also seeks specialist advice on snow conditions and the impact of the proposed development on nature conservation and forests. The operation and finances of companies are also under statutory supervision. Where a company cannot afford the replacement of old facilities, it may lose the right to operate them and would then be sold to another company with a sound financial base (Schmid, pers. comm.). As a result of these controls, applications are submitted with more detailed data than before. Very few applications, however, are approved (Schmid, pers. comm.).

Although individual applications for development are accompanied by often detailed data on snowcover, regional studies with the aim of identifying new sites use only data extrapolated from stations at lower altitudes. Krippendorf and Annasohn (1976), for example, used such data to suggest that snowcover was adequate if it had a duration of more than 100 days at an altitude of 1000m. Many of the ski areas in Switzerland, however, are located above 1000m and have snowcover lasting for more than 100 days (Eidgenossiche Institutes fur Schnee- und Lawinenforschung, 1982). This variable is redundant, therefore, and does not identify differences between sites. Similar variables have been used in many studies, including those by Elsasser et al. (1977) and Bridel (1970).

The situation is much the same in North America. Until the mid-1960s, applications were accompanied by few data on the consistency of snowcover. Many sites were identified by local people with knowledge of the area (see section 2.2.1). The US Forest Service (1973, 1975) now requests data on the quality of the snow, the depth of snow at critical locations (e.g., lift lines), wind patterns around the site and the frequency of bad weather.

The National Planning Guidelines for downhill skiing in Scotland (Scottish Development Department, 1984) encourage the provision of data on snowcover and local weather conditions with applications for permission to develop new facilities. They note the absence of any long-term measurements of snowcover, and request further work on snow and weather conditions. The guidelines represent the latest attempt to produce priorities for the development of facilities for downhill skiing in Scotland.

Since 1966, there have been sixteen official studies of various aspects of the development of facilities, including surveys of individual sites (Aonach Mor, Beinn a' Bhuird, Ben Wyvis, Drumochter and Grey Corries; see Figure 1.1), market surveys and statements of policy. In addition to these, there are the national planning guidelines and the report of the public inquiry into proposals to develop facilities for downhill skiing near Cairn Gorm (Scottish Development Department, 1983). Most interest has centred on Aonach Mor and Ben Wyvis throughout the period since 1966, although Beinn a' Bhuird figured prominently in the 1960s and Drumochter in the early/mid-1980s.

Although snow and weather conditions were examined in nine of these studies, only two (Scottish Development Department, 1967; Langmuir Ski Group, 1979) attempted to create new data and to compare a large number of sites. Remaining studies have used assumptions on snow and weather conditions which remain largely untested. This has led to general statements, such as "...skiing is confined to deep, sheltered corries where wind-blown snow gathers" (Baker and Gordon, 1980; p.14), which precludes the successful development of facilities at Glencoe, Glenshee and the Lecht, and "...Braeriach is the best site in Scotland because of the consistent snow in the northern corries" (Hunter, 1964; p.121). Results from the analysis of winter weather and the supply of snow over the period 1954/5 to 1983/4 (see Chapter 4) contrast sharply with many statements in these and other studies, particularly with respect to the frequency of wind directions and the supply of snow.

A major argument put forward by proponents of the development at Lurchers Gully (Scottish Development Department, 1983), was that snow and slope conditions at the site were adequate enough to support the development. Opponents to the scheme noted that data on the conditions of snow and weather were limited and that the "...developers' confidence in the snow holding ability of Coire an t-Sneachda and Coire an Lochain is based on his experience rather than on measurement" (Scottish Development Department, 1983; para. 4.13). The North East Mountain Trust (1983) noted that developments were still approved with very inadequate data on the duration of snowcover or in its complete absence.

With the exception of the Cairngorm Area Report (Scottish Development Department, 1967), no attempts have been made to identify sites with consistent snowcover in the Scottish Highlands. This has led to differences of opinion, for example, that "...the list of potential skiing areas is incomplete" (Langmuir Ski Group, 1979; p.9); and that "...there is broad agreement on a short-list of worthwhile alternatives for development" (Baker and Gordon, 1980; p.4).

The Cairngorm Area Report (Scottish Development Department, 1967) attempted to assess the potential of various sites in the Cairngorm Area (the area covered by the report could be defined more accurately as the Eastern Highlands of Scotland). The investigating committee defined the primary characteristics of a snowfield to be sufficient snow; suitable area and gradient to allow lifts and tows to operate; a capacity of 1000 persons and some degree of protection from the prevailing wind.

Green (1968, p.207), a member of the committee, noted that there was "...too much difference of opinion between individual skiers to make it possible to produce an agreed statement from their evidence..." on which sites were best. The committee used maps of vegetation (McVean, 1958), therefore, to identify areas of Nardus stricta which were thought to coincide with areas generally observed to have the longest snowlie (Green, 1968). The committee used aerial photographs taken by the Royal Air Force (RAF) on 1.4.65 (see section 2.4.3) to confirm which sites had the largest snowfields on that date. McVean and Lockie (1969, p.101) commented upon the Cairngorm Area Report and suggested that little information existed on the consistency of snowcover and that meteorological studies be given priority in order to put the "...assessment of snow potential on a firm basis". Unfortunately, neither the Cairngorm Area Report or any subsequent reports present long-term data on the consistency of snowcover or compare sites on a quantitative basis.

The data usually incorporated into studies of the potential of sites for downhill skiing are the amount of snowfall and the duration of snowcover recorded at weather stations near to the site(s). Data are extrapolated usually from the altitude of the station to that of the proposed development. Examples include the reports by Parnell (1974), Baker and Gordon (1975, 1980) and Davison (1982). In Scotland, the use of general increases in the duration of snowcover with altitude (e.g., Manley, 1971; Jackson, 1978) is of little value, as snowcover within gullies can last up to two months longer than snow on exposed slopes, while some late-lying snowfields face due south (e.g., on Beinn a' Bhuird).

It is recommended often, therefore, that observations be collected which are specific to a site. Martinelli (1976) and Owens and Prowse (1979) have put forward guidelines on the type of data required. The most useful data include the density, depth and duration of snowcover, particularly during the Christmas and New Year period; the frequency of snowfalls during the winter; the frequency of weather that would close lifts and tows (e.g., strong winds, fog, avalanches and warm weather); and localised wind patterns on a given mountain.

These data must be collected over several years at a specific site to be valid; Watson and Watson (1984) have suggested a minimum of five years. Such data must be provided with proposals to develop sites in Switzerland and North America, so it appears reasonable that such controls be applied in Scotland, where the resources are less favourable. Even then, it is difficult to compare the results with those for other sites owing to the shortage of data for mountain areas.

If the consistency of snowcover, and weather conditions, at a site are to be measured, any developer must be reasonably certain that the site is a good one owing to the cost and length of time involved in collection of the data. A method is required, therefore, which allows the potential of sites to be compared quantitatively and helps to identify sites where further, more detailed, study would be worthwhile.

2.4 SOURCES OF DATA ON THE CONSISTENCY OF SNOWCOVER.

2.4.1 Introduction

The last two sections identified the importance of the consistency of snowcover on the profitability of ski areas and found that its use in planning has been limited and often based on insufficient data and on assumptions that are implicit. This section examines the sources of data on the consistency of snowcover which are presently available.

2.4.2 Extrapolation of data from low altitudes

The most commonly used data on the consistency of snowcover are those recorded at stations at low altitudes. These data are extrapolated with reference to whatever data exist for stations at higher altitudes. The extrapolated data are then compared with some standard or figure which is deemed sufficient for downhill skiing (e.g., a minimum of 100 days snowcover). Manley (1969) and Jackson (1978) calculated that the duration of snowcover increased by 16 days for every 100m rise in altitude from data collected at altitudes of up to 400 metres and observations of the snowline on several mountains in Scotland. These data, and the gradients, have been used by Parnell (1975), Baker and Gordon (1975, 1980) and Davison (1982b) for predicting the length of the season.

The Northern Sports Council (1973) used a regression equation based on a strong correlation ($r = -0.878$) between the monthly mean air temperature and the number of days in a month with snow lying at 0900 hours at Moor House to predict the duration of snowcover in the northern Pennines. Land above 800m was predicted to have an average 100 days of snowcover a year. This finding, however, does not differentiate between sites above 800m and so cannot be used to compare them.

The use of data extrapolated from stations at low altitudes has not been restricted to Great Britain, being used also in Switzerland (e.g., Krippendorf and Annasohn, 1976; Elsasser et al., 1977) and North America (e.g., Farnes, 1971; Crowe et al., 1975). The extrapolation of data has four shortcomings:

1. it is based usually only on altitude, although the duration of snowcover is related to many other factors including the angle and aspect of a slope and the amount of snowfall;
2. it assumes that snowfall and the depth of snow increases constantly with altitude (the influence of drifting is held constant);
3. it assumes that all sites within a region receive the same amount of snowfall (holding altitude constant); and
4. it cannot be used to differentiate between sites of the same altitude.

A further problem is the paucity of data for many upland areas, including the Eastern Highlands of Scotland, that can be used to validate the extrapolation. No long-term data exist for temperature or precipitation for land above 400m (see Chapter 4) and observations of the snowline are only available for Ben Macdhui (viewed from Achnagoichan and Derry Lodge). Records for mountains elsewhere in Scotland are fragmentary, the only long-term records being for Ben Vane (since 1964/5) and Creag Meagaidh (since 1961/2).

2.4.3 Aerial photographs and Landsat scenes

The consistency of snowcover could be measured from sequential aerial photographs or Landsat scenes, if they were frequent and covered a number of sites. The Cairngorm Area Report (Scottish Development Department, 1967) used a set of aerial photographs taken by the RAF on 1.4.65 for this purpose, although only one set of photographs was used. Photogrammetric techniques could be used to measure the depth of snow at particular locations (Meister, 1983), although this procedure is time-consuming because the photographs need to be at a large-scale so large areas cannot be surveyed. Landsat scenes can be interpreted to provide data on the extent of snowcover over large areas but not, at present, on the depth of snow. Scenes have been utilised for the prediction of runoff in mountain areas (see Colwell, 1983 for a review) and to determine the quality of the snow at ski areas in New Zealand (Thomas et al., 1979).

To be of value, the aerial photographs should cover a large number of sites that can then be compared (Landsat scenes cover the whole of the study area) and the amount of snowcover should not be total, i.e., there must be differences between the sites, because if all sites had complete snowcover then no information could be derived as to which site had the most consistent snowcover. The ideal set of aerial photographs would cover the entire study area and would have been taken one or two weeks into a thaw such that the shallow snowcover had melted with only deep snow remaining.

Table 2.4 shows a list of all aerial photographs with snowcover over a large part of the study area. Four sets of aerial photographs (14.4.67, 4.11.68, 21.11.69 and 7.11.67) show snowcover almost complete above an altitude of 600m. The set for 4.2.55 shows thin new snowcover lying on old, deep drifts which are, unfortunately, difficult to measure. The photographs taken on 28.1.69 and 8.5.78 cover too few sites to be of any use. Four sets of photographs (18.4.55, 1.4.65, 25.4.68 and 13.4.81) are suitable in terms of the extent of snowcover and coverage of the sites, although only the set for 1.4.65 covers all of the sites. Those for 18.4.55 and 13.4.81 cover the Cairngorm Mountains and those for the 25.4.68 cover the SE Grampians and Beinn a' Bhuird/Ben Avon.

Table 2.5 shows a list of Landsat scenes which do not have problems of linestart (where part of the scene is missing), are not partially or completely covered by cloud and are available from the Royal Aircraft Establishment (RAE) at Farnborough. Five additional scenes (right-hand column in Table 2.5) are not available in this country and so would need to be ordered at considerable expense through RAE Farnborough. The scenes for 28.2.77, 5.1.79 and 23.2.80 show almost complete snowcover above 600m. The two remaining scenes (20.4.76 and 3.4.81) meet all of the requirements and have also been geometrically rectified to fit the National Grid by the RAE Farnborough (the 20.4.76 scene was rectified to a pixel size of 50m by 50m; the 3.4.81 scene to one of 100m by 100m). The Macaulay Institute for Soil Research and RAE Farnborough mapped the snowline on both scenes at a scale of 1:50,000 for the Highlands and Islands Development Board.

Although NOAA satellite scenes are more frequent and are

Table 2.4: List of aerial photographs covering all or part of the study area and showing snowcover

Date	Scale	Ref. number	Area covered
4.2.55	1:10,000	540/RAF/1524	Cairngorm Mountains
18.4.55	1:10,000	82/RAF/1151	Cairngorm Mountains
1.4.65	1:54,000	58/RAF/6677	Eastern Highlands
14.4.67	1:62,000	58/RAF/7986	Eastern Highlands
25.4.68	1:35,000	543/4276	SE Grampians/E. Cairngorms
13.4.81	1:50,000	13/5804	Eastern Highlands
4.11.67	1:54,000	58/9127	Eastern Highlands
21.11.69	1:62,000	58/0081	Eastern Highlands
8.5.78	1:39,900	39/5388	N. Cairngorms
7.11.67	1:17,500	58/8402	SE Grampians
28.1.69	1;56,000	58/9326	S. Grampians

Table 2.5: List of Landsat scenes covering the Eastern Highlands of Scotland and showing snowcover

Date	Path	Row	Date	Path	Row
20.4.76	222	20	14.1.79	222	20
3.4.81	222	20	1.2.79	222	20
23.2.80	222	20	18.3.79	222	20
28.2.77	221	20	5.5.80	222	20
5.1.79	222	20	20.4.81	221	20

widely available in this country, they have a spatial resolution of only one kilometre (i.e., the size of each pixel is 1km by 1km), which is of little use in any study of individual sites.

They may be valuable, however, in any study of the regional patterns of the supply of snow (see Chapter 8).

From a possible collection of 21 sets of aerial photographs and Landsat scenes, only six meet the requirements of coverage and extent of snowcover. This reduces their potential use in identifying sites with the most consistent snowcover, as the number is too small to provide meaningful results. They could provide data, however, for use in the validation of results from the use of one of the other methods.

2.4.4 Mapping of vegetation

McVean (1958) noted that there was a link between the type of vegetation and areas of consistent snowcover. Nardus stricta was found to be present at the sites of late-lying snowpatches, although the boundaries of these vegetation communities were less sharply defined than in continental regions because of snowcover in the Scottish Highlands is less reliable. The maps of Nardus vegetation published by McVean (1958) were used in the Cairngorm Area Report (Scottish Development Department, 1967) as they were thought to provide the most objective indicator of consistent snowcover (see section 2.2.2). The site with the largest extent of such vegetation should have the most consistent snowcover.

Watson (see Scottish Development Department, 1983) noted, however, that these communities often include other species which makes measurement and interpretation difficult. McVean and Ratcliffe (1962, p.59) noted that below 700m in the Eastern Highlands, Nardetum sub-alpinum occurs on hills which have carried considerable numbers of sheep for a long time, a situation that may lead to some mis-interpretation of the importance of Nardus vegetation at altitudes of 600m to 700m. Watson measured the extent of "snowpatch vegetation" in Lurchers Gully, Coire an Lochain, Coire an t-Sneachda, Coire Cas, Coire na Ciste and Coire Laogh Mor and argued that the second and third locations (the sites for the proposed development of facilities near Cairn Gorm) had the least consistent snowcover. Walder (1983) compared the disappearance of snowcover with patterns of vegetation in the Dischma Valley, Switzerland and found that it was earliest on Calluna heath (heather) and latest on Empetro-Vaccinietum. The date for the disappearance of snowcover on Nardus stricta was an average one.

Vegetation can be mapped using a combination of ground survey and aerial photographs. The Nature Conservancy Council has begun a programme of mapping vegetation within all National Nature Reserves and Sites of Special Scientific Interest in the Scottish Highlands. Only the Drumochter Hills SSSI, however, has been mapped to date. The mapping of snowpatch vegetation at a large number of sites would require knowledge of the interpretation of aerial photographs (i.e., ability to identify areas of snowpatch vegetation) and considerable time to check the maps in the field.

The use of data on the extent of snowpatch vegetation is not without problems. Although indicative of long-lying, and therefore consistent, snowcover, the actual extent of snowpatch vegetation is quite small relative to the size of each site. The vegetation is confined to steep leeward slopes and gullies and may not be truly indicative, therefore, of the consistency of snowcover at each site, i.e., they represent only small-scale topographic features at each site.

2.4.5 Opinions of local people and skiers

Local people and, to a lesser extent, cross-country skiers, may have knowledge of the location of sites with consistent snowcover based on long experience through living in or visiting the area. This method was widely used to identify sites for development in Switzerland and in North America until just after the Second World War (see section 2.2.1). From these opinions, sites with consistent snowcover may be identified and ranked, so providing a short-list of sites for more detailed investigation.

It may be quite difficult, however, to get accounts on the location of these sites which are accurate. Old people, for example, may remember particular areas only or their opinions may be biased towards particularly snowy or rainy winters. Many local people with knowledge (e.g., stalkers, shepherds) have died in recent years and have been replaced by younger people with little experience of snow conditions within their areas (Watson, pers. comm.).

All skiers tend to have their own favourite area(s) for skiing which may bias their opinions of other areas. Such judgements will be subjective and not based on any data, and are therefore impossible to compare (Green, 1968). There is also the danger that this method would perpetuate existing views and beliefs.

2.4.6 Study of the morphology of sites

From a study of three winters (1977/8 to 1979/80) in the

Cairngorm Mountains, Ward (1981) found that almost all snowfall is accompanied by wind. Data from the automatic weather station on the summit of Cairn Gorm (1245m) shows that the mean wind speed in winter is 15.1m/s (see Table 3.1). The drifting of snow, therefore, will be important, i.e., during strong winds snow will be eroded from windward slopes and deposited on leeward slopes.

The drifting of snow and, to a lesser extent, the supply and retention of snow, is controlled by the speed and direction of the wind, the amount and type of precipitation and the morphology of the land surface (McKay, 1970). The angle, elevation and aspect of slopes, for example, exert considerable influence on the drifting of snow (Berg, 1977; Radok, 1977), thus the steeper the angle of a slope (up to a certain angle at which the snow would avalanche), the deeper the deposit of snow (Tabler, 1975). It might be possible, therefore, to predict which sites have the most consistent snowcover by measuring the morphology of each site. As the study would be quantitative, sites could be compared. The most difficult problem to overcome would be the definition, measurement and analysis of the data.

The influence of the morphology of the land surface on the consistency of snowcover has been recognised by people involved in skiing in Scotland. Clyde (1981), for example, suggested that sites should have deep-cut gullies to entrap and then retain snow, face north-west to east, lie above 700 to 760m and have an angle of slope of between 8^0 and 26^0. The Cairngorm Area Report (Scottish Development Department, 1967) recognised that most snow collects in gullies.

No attempt has yet been made to compare the morphology of sites for the purpose of identifying sites with the most consistent snowcover. Indeed, the processes that control the supply, entrapment and retention of snow in windy environments are not widely understood (in this country or elsewhere) and the literature which specifically addresses the problem of the drifting of snow is sparse (Barry, 1981). This may create a problem in that it is necessary for the researcher to improve the knowledge of the processes involved and then use this knowledge to improve the method, i.e., the researcher would not be concerned only with the measurement of the natural potential of sites for downhill skiing.

2.4.7 Discussion

All five sources of data have limitations and problems. The most important requirement is for data that can be used to measure the natural potential of a large number of sites (on a relative basis) and that produce results that can then be validated and verified. The main problem is one of a paucity of data on snowcover and weather conditions for land above 400m in the Scottish Highlands. Data that can be derived from aerial photographs, Landsat scenes, maps of vegetation and the opinions of local people and skiers are limited and fragmentary. These data could be used, however, to validate, verify and interpret the results derived from the use of data on the morhology of each site.

The procedure by which sites with the most consistent snowcover can be identified and compared is shown in Table 2.6. The procedure involves seven steps beginning with the identification of the processes that control the consistency of snowcover and ending with the critical examination of the results. The last step should provide information which can be

Table 2.6: Procedure for the identification of sites with the most consistent snowcover.

STEP 1: Identify the processes that control the consistency of snowcover.
STEP 2: Identify variables to represent these processes.
STEP 3: Measure variables using OS maps.
STEP 4: Analaysis of the data.
STEP 5: Translate the data into accurate measures of potential.
STEP 6: Validation and verification of the results.
STEP 7: Critical examination of the results.

used to improve the first six steps. The most contentious steps are the first two and the fifth. It was noted earlier that knowledge of the processes that control the consistency of snowcover in windy environments is poor and this is particularly true for the Scottish Highlands. Arguably, the most difficult step is the valid measurement of potential (Step 6), as units of measurement are largely unexplored and are usually based on implicit assumptions which are never tested. This problem is reviewed in more detail in Chapter Three.

For this reason emphasis will be placed on the validity of the results. Data on the consistency of snowcover will be collected from aerial photographs, Landsat scenes and fieldwork. The results will be verified by reference to the published opinions of skiers and the extent of snowpatch vegetation at selected sites.

2.5 CONCLUSIONS

1. The consistency of snowcover has a strong influence on the profitability of ski areas in Switzerland, North America and Scotland.

2. Potential can best be measured as a relative phenomenon, i.e., that site A is better than site B. A large number of sites must be compared, therefore, to determine which has the most consistent snowcover.

3. The paucity of data on the consistency of snowcover has meant that planning is based on general statements and assumptions, rather than on facts.

4. Detailed data on the consistency of snowcover and weather conditions are now required to be submitted with proposals to develop new facilities for downhill skiing in Switzerland and North America.

5. Developers and planners are unable, at present, to compare the natural potential of sites objectively and quantitatively.

6. Data based on the influence of the morphology of the land surface on the drifting of snow are the most useful available for the measurement of natural potential. Results will be validated and verified from several sources of secondary data.

The next chapter will identify the processes that control the consistency of snowcover at a site and variables to represent these processes. A method for translating the data into accurate measures of potential will be described.

CHAPTER 3: THE SUPPLY, ENTRAPMENT AND RETENTION OF SNOW

3.1 INTRODUCTION

The previous chapter established the need to identify sites with the most consistent snowcover and argued that data based on the influence of the morphology of the land surface on the supply, entrapment and retention of snow was the most suitable to meet this need. This chapter identifies the processes that control the consistency of snowcover and variables to represent them. A method for translating the data into accurate measures of potential is also described.

3.2 IDENTIFICATION OF THE PROCESSES THAT CONTROL THE CONSISTENCY OF SNOWCOVER.

3.2.1 Introduction and background

The aim of this section is to identify the processes that control the consistency of snowcover. In windy environments, there are three main areas of interest: the supply of snow to a site and the entrapment and retention of snow at a site. The consistency of snowcover is a product of the interactions between the amount and type of precipitation, the speed and direction of the wind and the morphology of the land surface (McKay, 1970; McKay and Gray, 1981). Where there is little or no wind (i.e., less than 5m/s), snow tends to fall evenly over the land surface (this snow, however, may be redistributed by the wind at a later date). As the wind speed increases there is a greater tendency for snow to be deposited on leeward slopes.

Föhn (1980) measured the depth of snow on the windward and leeward slopes of a ridge crest and also on horizontal land, on three occasions after snow fell during wind speeds of 5 to 13m/s. From these measurements, Fohn developed an equation which predicts the average "wind-snow" depth, which is the surplus accumulation of snow on leeward slopes compared to drift-free horizontal areas. The equation is:

$$Hns = k\ u^3 \text{(metres per day)};\ u < 20\text{m/s}.$$

where Hns is the wind-snow depth, u the wind speed and k a constant (8×10^{-5}). Figure 3.1 shows a plot of these values. The relationship is exponential, i.e., the value of Hns increases rapidly with increasing wind speed. The value of Hns, for example, is twice as great at 25m/s than it is for 20m/s. During

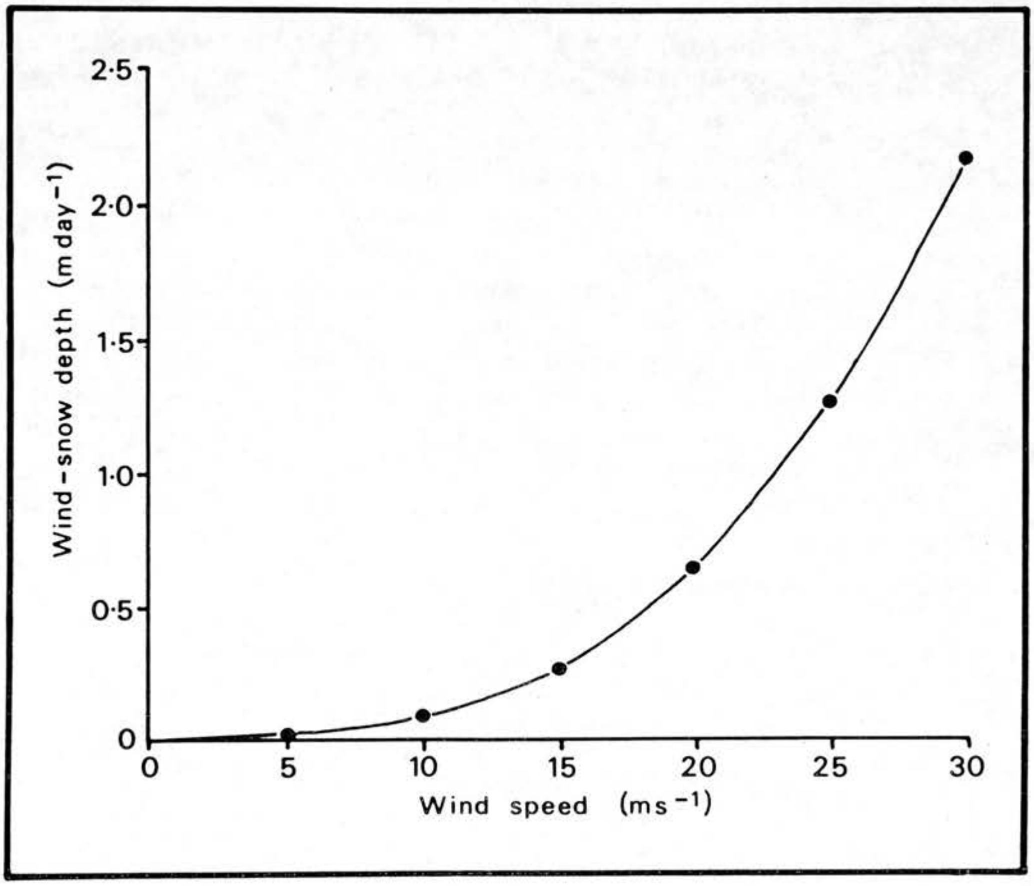


Figure 3.1: Influence of wind speed on the drifting of snow.

on the 5.1.84 at Glenshee, depths of snow were measured on leeward slopes to be approximately three metres but less than half a metre on windward slopes. The snow fell during winds from the west with a geostrophic speed of up to 38.5m/s (see Appendix 2).

The drifting of snow tends to be greater, therefore, on massifs where wind speeds are high. Table 3.1 compares wind speeds recorded in the Scottish Highlands with those recorded in other mountain areas. This table can be used to estimate the importance of drifting in the Highlands compared to other areas for the purpose of identifying relevant literature.

Wind speeds at relatively low altitudes in the Alps (e.g., pre-Alps, Stillberg) and in the Rocky Mountains (e.g., Marmot Creek, Loveland Basin) are much lower than those recorded on Cairn Gorm. Wind speeds during snowfall are low in these locations (Martinelli, 1965; Storr, 1973). The areas with the nearest equivalent wind speeds are the high ridges and summits of the Rocky Mountains (e.g., Niwot Ridge, Mines Peak). Mt. Washington has very high mean wind speeds, probably owing to it being the highest mountain in north-east U.S.A.. Wind speeds in the coastal regions of Antarctica are constantly high (Loewe, 1971) but those on the ice cap (Budd et al., 1966) are less than those in the Scottish Highlands. Data for the Arctic are very limited, although Woo and Sauriol (1980, p.38) suggested that the "...process of snow drifting rather than the absolute amount of snowfall plays the dominant role in affecting snow distribution".

Table 3.1: Comparison of wind speeds in selected mountain areas of the world.

Country	Location	Details of wind speed	Reference
Scotland	Cairn Gorm (1245m)	Mean wind speed (December to April) of 15.1m/s.	Heriot-Watt Univeristy (1983)
Antarctica	Byrd Station	Mean wind speed of 7.6m/s.	Budd et al. (1966)
Antarctica	Port-Martin (50m)	Mean annual wind speed of 18m/s	Loewe (1971)
Canada	Marmot Creek (1585 - 2800m)	80% of all snow falls with wind speeds of less than 4.0m/s	Storr (1973)
Japan	Mt. Aso (1143m)	8.1% of all days in January have wind speeds of more than 15m/s.	Yoshino (1975)
Switzerland	Pre-Alps (1300m)	Mean wind speed of 2.5m/s in winter	Meiman (1971)
Switzerland	Stillberg (2200m)	Mean wind speed of 1.9m/s in winter	Nageli (1971)
U.S.A.	Niwot Ridge (3750m)	Mean wind speed of 11m/s; 50% of all days have wind speeds of more than 18m/s	Ives and Fahey (1971)
U.S.A.	Rocky Mountain National Park (3500m)	Mean wind speed of 16.1m/s in January, 7.1m/s in April	Glidden (1982)

Table 3.1 continued

Country	Location	Details of wind speed	References
U.S.A.	Mt. Washington (1916m)	Mean wind speed of 20.6m/s in January, 16.1m/s in April	Glidden (1982)
U.S.A.	Loveland Basin (3630m)	Daily wind speeds during five weeks of heaviest drifting seldom exceed 9m/s.	Martinelli (1965)
U.S.A.	Mines Peak (3808m)	Mean wind speed of 15.4m/s in January	Barry (1981)
U.S.A	Tokositna, Alaska (900m)	4% of all wind speeds exceed 9m/s	Sno-Engineering (1981)

In summary, areas which are similar to the Scottish Highlands include the ridges and summits of Rocky Mountains, the coastal mountains of North America, the high Arctic, and inland Antarctica. Areas which are less harsh include the lower slopes of the Alps and Rocky Mountains, and those that are harsher include Mt. Washington and the coastal areas of Antarctica.

3.2.2 Supply of snow

If the amount and type of precipitation and the speed and direction of the wind are known for any day then it should be possible to calculate the relative amount of the supply of snow to sites. A site facing north-west, for example, is leeward to winds from the south-east, but is windward to winds from the north-west. If most snow comes from the south-east, then sites facing north-west would receive a high percentage of the total possible amount of drifting snow. Ward (1981) developed a method by which the amount of snowfall and the wind speed could be converted into amounts of "snowdrift". The proportion of snowdrift for each direction could then be calculated. This method is discussed in greater detail in Chapter 4.

The redistribution of deposited snow by the wind is governed by the same principles as drifting during snowfall. Studies in Antarctica by Budd et al. (1966) showed that the amount of snow carried by the wind increases exponentially with wind speed. The calculation of "wind-drift" by Budd et al., however, pays no attention to the extent of fetch upwind of a site. Takeuchi (1980) suggested that the amount of snow transported and then deposited by the wind varies according to the length of fetch.

Over the first 200m of fetch, Takeuchi found that there was net erosion of snow, between 200m and 350m erosion was equal to deposition and beyond 350m there was net deposition. Very few studies have measured wind-drift on massifs, where areas of flat land are rare, although Kotlyakov and Plam (1965) suggested that the amount of wind-drift on massifs is very limited because the relief is highly dissected, such that the distance usually travelled by crystals of snow blown by the wind is only 100m and, in rare cases, up to 500m. In the Eastern Highlands of Scotland, however, the mountains are relatively rounded and this, together with the high wind speeds and occasionally low relative humidity (Green, 1967), suggest that wind-drift may be important.

Altitude is considered by many authors to be the most important factor affecting snowcover (e.g., Manley, 1969; Meiman, 1970; Jackson, 1978; McKay and Gray, 1981). The influence of altitude on the supply of snow is twofold:

1. the amount of precipitation increases with altitude; and
2. the air temperature decreases with altitude, so the percenatge of precipitation falling as snow increases.

The only detailed study of gradients of precipitation in the Scottish Highlands is that by Ballantyne (1983) for An Teallach in Wester Ross, while less detailed work has been carried out by Dybeck and Green (1955) and Gloyne (1968). These studies have been concerned only with rainfall rather than snowfall, because the latter is difficult to measure in mountain areas owing to the influence of drifting and of snow being blown over a measuring gauge rather than into it (Goodison et al., 1981). Waring (1981) tried to solve this problem at Plynlimon in Wales by using pressure plates and specially adapted gauges, but with only limited success. A further problem is that of the spatial variability of precipitation. Sandsborg (1970) noted from a study of the distribution of rainfall over a small hillock (4m high) that in wind speeds of more than 5m/s the amount may vary by up to 28% between windward and leeward slopes. Faced with such variability, any measurements are likely to be very site-specific. The Natural Environment Research Council (1975) commented that there was a lack of observing stations on high ground and this remains a valid point. No data exist by which the rate and nature of any increase in the amount of snowfall with altitude can be calculated.

Windflow over a massif must rise from sea level (or the base of the massif) to the summit, so orographic precipitation is important, and must also pass over a succession of ridges and valleys. Rhea and Grant (1974) developed an equation for this process which included the effects of large-scale vertical air mass movement over upwind barriers, convective activity and orographic lift, interception of precipitation by upwind barriers and exposure. The equation accounted for 90% of the variation in snowfall across the Rocky Mountains in Colorado using two variables: (1) the topographic slope that winds bearing precipitation must traverse on their last 20km of approach to a given station; and (2) the number of upstream barriers that the air must pass over (Rhea and Grant, 1974; p.182).

Although Taylor (1976, p.206) assumed that the British uplands were "...too low, narrow and discontinuous, even by

European standards, to modify weather systems in depth or generate their own particular climate with any regularity", the Eastern Highlands rise to over 1300m and are dissected by deep valleys which may create both orographic lifting and turbulence in the air over large areas. Pedgley (1970) studied the wind direction and distribution of precipitation over the Snowdonia massif and found that, depending upon the general wind direction, some valleys produced a funnelling effect or were sheltered, and that gradients of precipitation at the two ends of the massif were steep. Although widely studied for rainfall, the influence of massifs on snowfall has been neglected. It is assumed, therefore, that the same processes are at work.

As any barriers upwind of a site will have both windward and leeward slopes, snow will be deposited before the front reaches a site. The amount "depleted" will depend upon the height, width and slope of these barriers. Gentle leeward slopes are unlikely to deplete large amounts of snow,whereas steeper slopes (e.g., corrie headwalls) are likely to trap large amounts of snow.

There are three main processes that control the supply of snow to a site. The first is the relative supply of snow, which is based upon the wind direction and speed, the amount of precipitation and the directions for which a site is leeward. The second is the increase in the amount of precipitation (and the percentage falling as snow) with altitude and the third is the upwind depletion of snow as fronts move across a massif.

3.2.3 Entrapment of snow

The drifting of snow has been studied by many authors since the 1930s, although almost all have been concerned with snow-drift on horizontal surfaces. Most research has been located in Antarctica (e.g., Mellor, 1963; Budd et al., 1966; Radok, 1970) and Siberia (e.g., Dyunin and Kotlyakov, 1981). Although wind speeds in inland Antarctica are less than those in the Scottish Highlands, the terrain is generally flat so the study of drifting snow is a two-dimensional problem. This allows the flow of air to be more easily modelled (Föhn and Meister, 1983).

Since the mid-1970s, more attention has been given to the drifting of snow on the high summits of the Rocky Mountains and the Sierra Nevada in California with work by Berg (1977), Daly (1984) and Minnich (1984), and on ridge crests at 2500m in the Swiss Alps by Föhn (1980) and Föhn and Meister (1983). Föhn and Meister (1983) admitted that knowledge of the processes which control the drifting of snow is poor because data on wind and snowcover have been insufficient. Recent research has concentrated on drifting over ridge crests, therefore, where the flow of air can be modelled in two dimensions. Generally, however, there has been little research into the drifting of snow on massifs.

The basic control on the drifting of snow is the interaction between currents of air and the obstacles which they encounter (Kuz'min, 1963). When currents of air converge their speed, and hence their ability to transport crystals of snow, increases. The deposition of snow is reduced and snow may be eroded from the windward side of a mountain. Figure 3.2 shows the flow of air

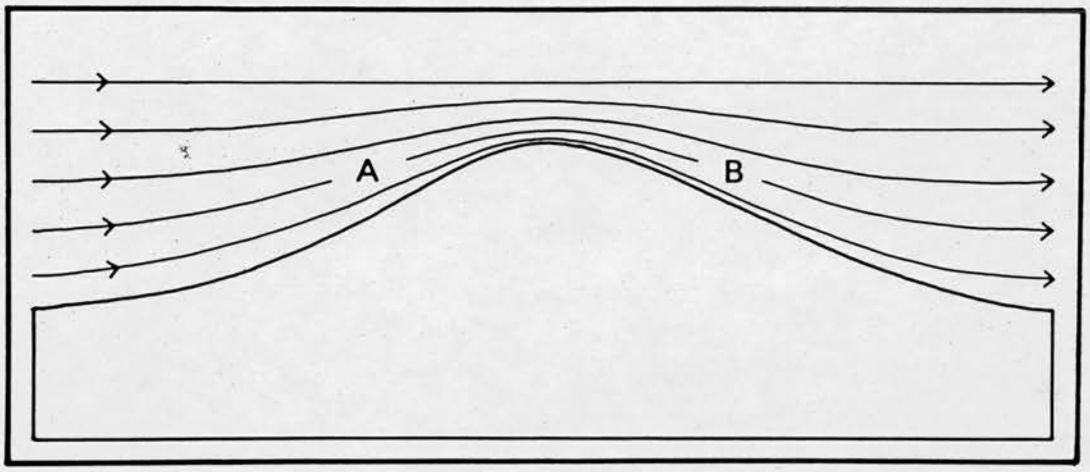


Figure 3.2: Flow of air over a rounded mountain summit.

Plate 1: Example of a rounded mountain summit (Cairn Gorm). The automatic weather station (see Chapter 4) can be seen on the summit.

over a rounded mountain summit, while Plate 1 shows the summit of Cairn Gorm as an example. The air becomes compressed at point A and so little or no snow is deposited, and erosion of deposited snow may occur. When the currents of air diverge (B) their speed falls and their ability to transport snow is reduced and snow is then deposited. Although Plate 1 shows snow which fell on 11.6.85 in light winds (from left to right), the snow is thinner at point A than at point B. A more detailed description of this process is provided by Kuz'min (1963), Mellor (1963) and Berg (1977).

The study of this process in two dimensions (e.g., on flat ground or the crests of ridge), allows theoretical explanations of the interactions between the wind and terrain to be derived accurately, although the need to collect detailed data has restricted research to a few sites only. The supply of snow and the morphology of the land around the site, therefore, have been neglected.

Using the principle of maximum equilibrium depths of snow behind small obstacles, Tabler (1975) produced an equation to predict the angle of the slope of a snowdrift from the angle of the slopes of the land upwind and downwind from the lip of the trap. The equation is:

$$Y = 0.25X_1 + 0.55X_2 + 0.15X_3 + 0.05X_4$$

where Y is the angle of the slope over the main portion of the drift, X_1 to X_4 are the angles of the ground slope over a distance of 45m upwind and 0-15m, 15-30m and 30-45m downwind of the lip of the trap respectively. This equation can be used to illustrate the influence of the angle of slopes on the drifting of snow. Figure 3.3 illustrates the influence of several gullies on the depth of snow. In examples A to D, the slopes downwind of the trap of the lip are changed. The deepest drifts are created in gullies which are steep-sided (e.g., A and D). Examples E to G show the influence of the slope upwind of the lip. As the apex angle of the lip is reduced the depth of snow increases because this exerts a greater separation of the currents of air. Small changes in the slope upwind and downwind of gullies, therefore,

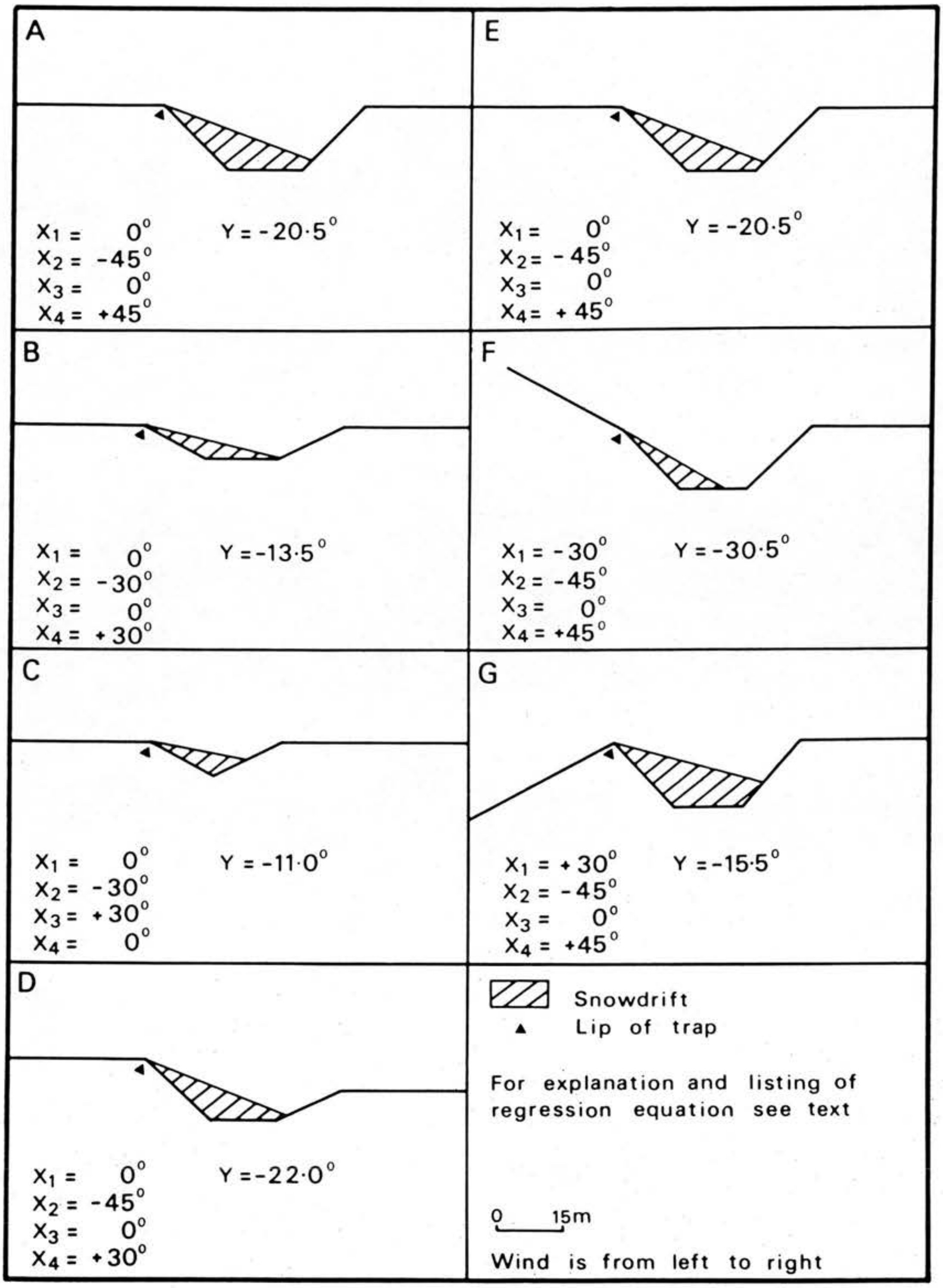


Figure 3.3 Influence of the morphology of gullies on the depth of snow.

can affect the ability of the gully to entrap snow.

The importance of small obstacles should not be underestimated. Nägeli (1971), for example, in a study of wind patterns at Stillberg (2200m) in Switzerland, found that ridges and gullies with a relief of 5m to 12m can modify the wind speed by up to 60% when the direction is perpendicular to the obstacle. The minimum change in slope necessary to induce drifting is 9^0 (Berg, 1977). The dominant control within all the above examples is the creation of turbulence in the air by the morphology of the land surface. The influence of the assymetry of gully side slopes on the entrapment of snow has not been studied. Kennedy (1976) suggested that in areas of prevailing easterly or northerly winds in the northern hemisphere, the optimum locations for the depth and persistence of snowdrifts would not coincide and so may cause assymetry.

The basic effect of turbulence in the air during snowfall is the deposition of snow on leeward slopes. Turbulence in the air is controlled by the morphology of the land surface and the speed and direction of the wind. Of particular importance is the depth, width and slope of the obstacle (McKay, 1970). Incised terrain induces considerably more drifting, therefore, than does less incised terrain. Figure 3.4 shows the influence of the morphology of gullies and drainage basins on the creation of turbulence in the air and on the drifting of snow. Point A in each example is where currents of air diverge and deposition occurs. The currents converge at point B. A deep gully (a) will induce greater turbulence and so more drifting than a shallow gully (b), which also holds true for deep drainage basins (c) compared to shallow

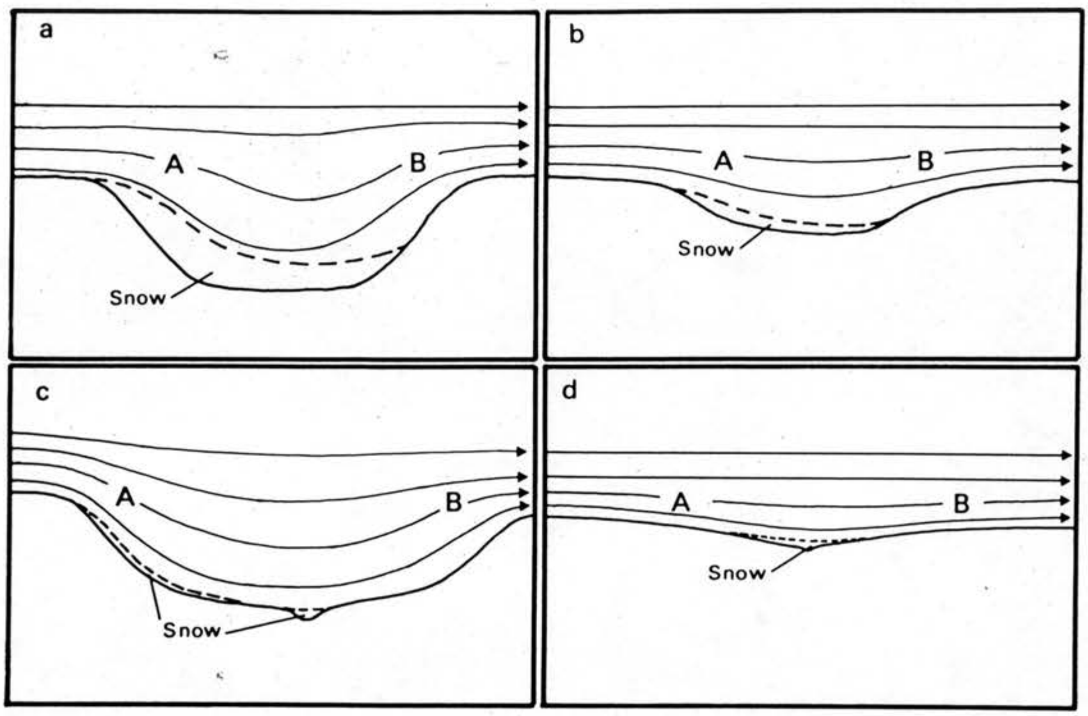


Figure 3.4: The influence of basin and gully morphology on the drifting of snow.

basins (d). The work of Tabler (1975), Berg (1977), Föhn (1980) and others suggest that the deeper a gully or basin is the higher its efficiency in trapping snow.

It is not quite as simple as this, however, as a shallow basin is more likely to have complete snowcover of equal depth because the relative absence of turbulence in the air will induce neither the drifting nor erosion of snow. A deep gully within a shallow basin is likely to have relatively deep snowcover because it is the only location within the basin at which large amounts of drifting can occur.

The entrapment of snow is controlled, therefore, by the interaction between currents of air and the morphology of the land surface. This interaction creates increased turbulence in the air which induces the deposition of snow on lee slopes. Most studies of the drifting of snow have been restricted to flat land or ridge crests and are site-specific. It appears, however, that the size, shape and orientation of the terrain is important.

3.2.4 Retention of snow

Temperature generally decreases by between 6^0 and 8^0C for every 1000m rise in altitude (Barry, 1981), so the rate of melt generally decreases with altitude (all other things being held constant). While the nature of the processes are widely understood, data on temperature and snowmelt are not widely available in the Scottish Highlands. The correlation between the duration of snowcover and altitude, however, increases with increasing range of altitude. Regression studies that have found altitude to be important have usually included sites over a wide range in altitude. Storr and Ferguson (1972) found that altitude (range from 1280m to 1840m) accounted for 98% of the variation in the amount of snowfall. Spreen (1947) obtained similar results in Western Colorado where the altitude of the stations ranged from 1380m to 3510m.

Most of the stations used in regression studies of snowcover in the European Alps and in North America have been located below the treeline where wind speeds and, therefore, drifting, are much lower than at sites above the treeline (see Table 3.1). When there is no wind, snow falls evenly over the land, so the influence of altitude on the amount of snowfall and the depth of snow is clearer. Where drifting is important the depth of snow does not equal the amount of snowfall, so the influence of altitude is less clear.

Moore and Owens (1984) found that 82% of snowmelt was accounted for by sensible and latent heat exchange during warm, windy weather and only 16% by global radiation. The study was located in the Southern Alps of New Zealand, where the climate in winter is similar to that in the Scottish Highlands (see section 4.4.2). Similar conclusions have been reached by Morris (1982, 1983) and Ferguson (1984) in the Scottish Highlands. The rate of exchange increases with increasing turbulence in the air (Obled and Harder, 1979). As noted earlier, turbulence in the air is controlled by the morphology of the land surface, so it is likely, therefore, that the terrain that induces drifting of snow also increases the rate of melt during warm, windy weather. This may well complicate the interpretation of results.

Received global radiation is a function of the angle and aspect of a slope, latitude and the day of the year and is influenced strongly, therefore, by the morphology of the land surface. The inclusion of global radiation in a study of snowcover is quite rare owing to the problem of measuring the amount of radiation over large areas. The aspect of a site is commonly used in its place (see Meiman, 1970, for a review). Computer programs are available (e.g., Williams et al., 1971; Dozier and Outcalt, 1979; Isard, 1983), however, by which global radiation can be calculated.

Temperature and the rate of melt generally decrease with altitude and this influences the consistency of snowcover. The received amount of global radiation can be an important component of melt, although in areas such as the Scottish Highlands, the rate of turbulent exchange is more important. Turbulent exchange is greatest on days with warm, windy weather and increased turbulence in the air. This process is influenced, therefore, by the morphology of the land surface.

The preceding review of the literature has identified processes created by the influence of the morphology of the land surface on precipitation, wind speed and direction, solar radiation and air temperature and that control the consistency of snowcover. Figure 3.5 shows these relationships. The five processes are (1) the supply of drifting snow, (2) the creation of turbulence in the air, (3) gradients of precipitation and temperature, (4) global radiation and (5) the upwind depletion of precipitation. Variables will be identified in section 3.3 to represent these processes.

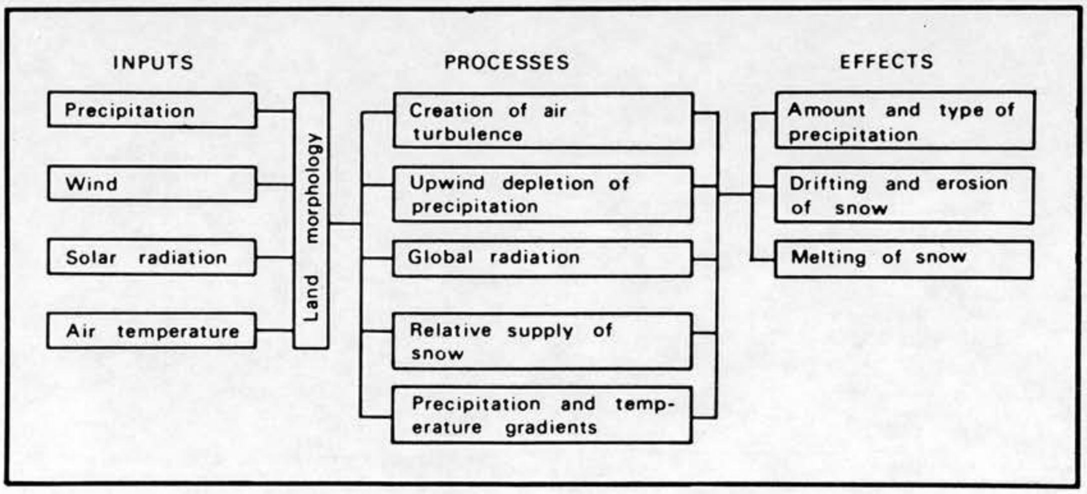


Figure 3.5: Influence of the morphology of land on the consistency of snowcover.

3.2.5 Regression studies of snowcover

The last section identified the processes that control the supply, entrapment and retention of snow. This section reviews the incorporation of these processes into regression analyses of snowcover.

Most studies of snowcover which have used regression analysis have used the following variables: altitude, angle of slope, aspect, exposure and the curvature of the slope (e.g., Spreen, 1947; US Army Corps of Engineers, 1956; Anderson and Pagenhart, 1957; Anderson and West, 1965; Hendrick et al., 1971; Storr and Ferguson, 1972; and many others). These variables usually account for between 58% and 98% of the variation in the amount of snowfall or depth of snow, even though they represent only gradients of precipitation and temperature and, to a lesser extent, turbulence in the air and global radiation. The data are usually measured at point locations such as weather stations and snowcourses, which are located below the treeline where wind speeds are lower than on exposed slopes above the treeline. Processes that tend to operate only in windy environments, therefore, are not important, particularly as the influence of altitude and aspect is clearer as their effects have not been modified.

These studies are of only limited use to this study owing to the stronger winds and the increased occurrence of drifting in the Scottish Highlands. Unfortunately, there have been few studies of snowcover in environments where drifting is important. A further problem is that this present study is concerned with landforms rather than point locations. The nearest equivalent approach is to divide an area into landscape units (e.g., flat areas, gullies, valleys, escarpments) which have relatively homogeneous depths of snow. The depth and density of snow on a random sample of each type of unit are measured and then extrapolated to all other units so that large areas can be surveyed quickly and at little cost. Although McKay and Gray (1981) suggested that this approach is widely used, a thorough review of the literature revealed few examples. Woo and Marsh (1978) used this method in the High Arctic where the landscape can be divided easily into units and the depth of snow can be measured in late-season owing to the absence of melt during the winter. As winter in the Scottish Highlands is a succession of thaws and snowfalls, this approach is of little use.

One of the few studies to look at landforms is that by Alford (1973), who measured the accumulation of snow in thirteen cirque basins in the Rocky Mountains and identified the existence of an "orientation gradient", which represented the differential redeposition of snow by the wind along an axis parallel to the mean trajectory of storms (i.e., similar to the relative supply of snow identified in section 3.2.2). This gradient accounted for 88% of the variation in the accumulation of snow.

Few studies of snowcover that have incorporated regression analyses have used data for massifs where wind speeds are high. Data are collected at snowcourses or weather stations which are usually below the treeline. These studies concentrate, therefore, on specific points rather than on landforms and few consider a large number of different sites. The variables most commonly used are altitude, aspect and the angle of slopes, so the processes identified in section 3.2 have been rarely analysed together in a single study.

3.3 IDENTIFICATION OF THE VARIABLES

3.3.1 The dependent variable

In Chapter One, a site with natural potential was defined as having consistent snowcover during the winter. The consistency of snowcover is in turn related to the depth of snow: the deeper the snow the longer it will survive (the retention of snow being held constant). The site with the deepest snow, therefore, is likely to have the most consistent snowcover. The depth of snow, however, has three problems associated with its measurement:

1. the need to create a representative measure of the depth of snow for stream channels which are up to 3km in length;
2. the length of stream channels dictate that only one can be measured on any one day, unless they are situated close together; and
3. although the depth of snow can be measured from aerial photographs, this process is time-consuming.

A variable is required that represents the depth and consistency of snowcover, but that can be measured at a large number of sites. Figure 3.6 shows the pattern of snowcover on Beinn a' Bhuird (A) and Glas Tulaichean (B) on 25.4.68 and drawn from aerial photographs. There is a clear difference in the areal extent of snowcover between the two mountains, which suggests that the snow is deeper, and so more consistent, on Beinn a' Bhuird. The lowest altitude of snow at Allt a' Choire Ghuirm, for

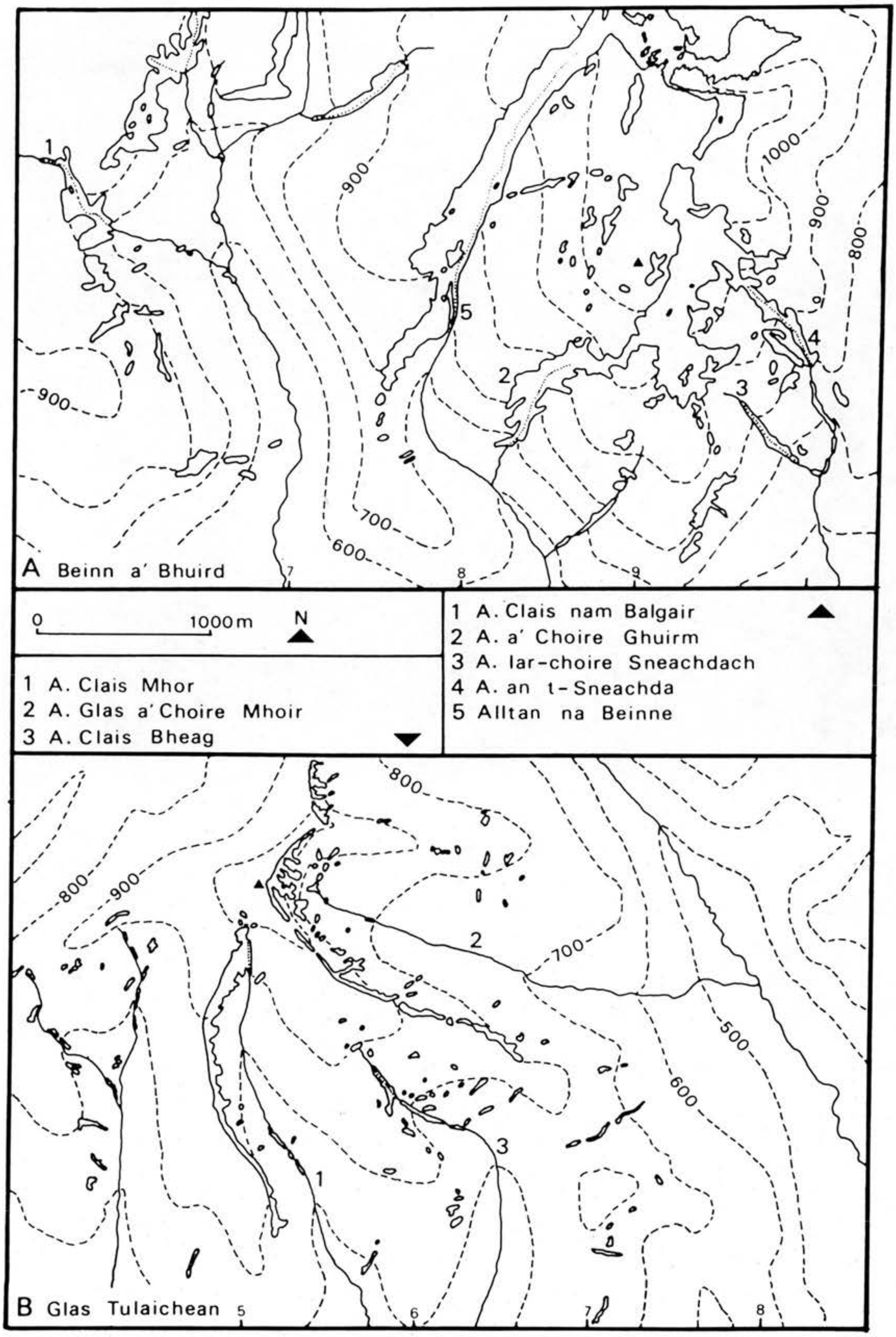


Figure 3.6: The extent of snowcover on Beinn a' Bhuird and Glas Tulaichean, 25.4.68.

example, is 670m, while at Allt Clais Mhor it is 710m (i.e., the difference is small). The amount of snow in each gully above these altitudes, however, at the two sites is 78.1% and 10.9% of the total length of the gully respectively. This latter variable appears more indicative of the actual amount of deeper snow at each site. Table 3.2 shows the extent of snow in each of the gullies shown in Figure 3.7 expressed as a percentage of their length.

Table 3.2: Extent of snowcover in gullies on Beinn a' Bhuird and Glas Tulaichean, 25.4.68

Beinn a' Bhuird	%	Glas Tulaichean	%
A. Clais nam Balgair	66.3	A. Clais Mhor	10.9
A. a' Choire Ghuirm	78.1	A. Glas a' Choire Mhoir	5.7
A. Iar-choire Sneachdach	74.7	A. Clais Bheag	29.8
A. an t-Sneachda	85.7		
Alltan na Beinne	64.7		

To represent the consistency of snowcover, the extent of snowcover in each gully must be based on two assumptions.

1. The extent of snowcover in a gully is equivalent to the depth of snow in that gully (unless there are differences in the ability of the sites to retain snow). A gully with a low value (e.g., Allt Clais Mhor) would have relatively shallow snowcover during the season.

2. That weather conditions during the winter are similar for the entire area covered by the photographs, i.e., the amount of precipitation on Beinn a' Bhuird is similar to that on Glas Tulaichean. The lack of data on precipitation above 400m means that its influence must be held constant (see Chapter 8).

The above arguments raise two important points for the construction of a method of analysis. The first is that natural potential can be validated only on a relative basis, i.e., with reference to a large number of sites: the extent or depth of snow in one gully is a meaningless value if it is not compared with the values at other sites. The second is that the variables must be chosen to maximise or minimise the consistency of snowcover, e.g., a deep gully should have deep snowcover, a shallow gully should have shallow snowcover.

3.3.2 The independent variables

The review of literature identified five processes that control the consistency of snowcover. This section will identify variables to represent these processes.

The basic control on the creation of turbulence in the air is the degree of incision of the land surface: the more incised the terrain the greater the turbulence. This process can be represented by the morphology of gullies and drainage basins. The analysis of the morphology of drainage basins has long been studied by geomorphologists and a large amount of literature exists (e.g., Cooke and Doornkamp, 1971; Gregory and Walling, 1976; Richards, 1981). The morphology of gullies has not been studied as widely and research has tended to be concentrated on stream channels (i.e., that part of the gully occupied by the stream). The basic dimensions of a gully or basin are its width, depth and side slope and can be measured either from maps or through fieldwork. Owing to constraints of time, the measurement of morphology in the field could not be undertaken. The ability to measure variables is constrained, therefore, by the limitations of Ordnance Survey maps. One of these is that the boundary or lip of the gully cannot be identified for many of the sites. An artificial boundary was required which, unfortunately, ruled out the measurement of gully width and apex angle (see section 5.2.3).

The full definition of gully side slope is the angle of the sides of a gully measured at transects across it at intervals of 100m down from its source. The values for each transect are summed and divided by the number of transects to provide a mean value. Figure 3.7 shows how gully side slope is measured.

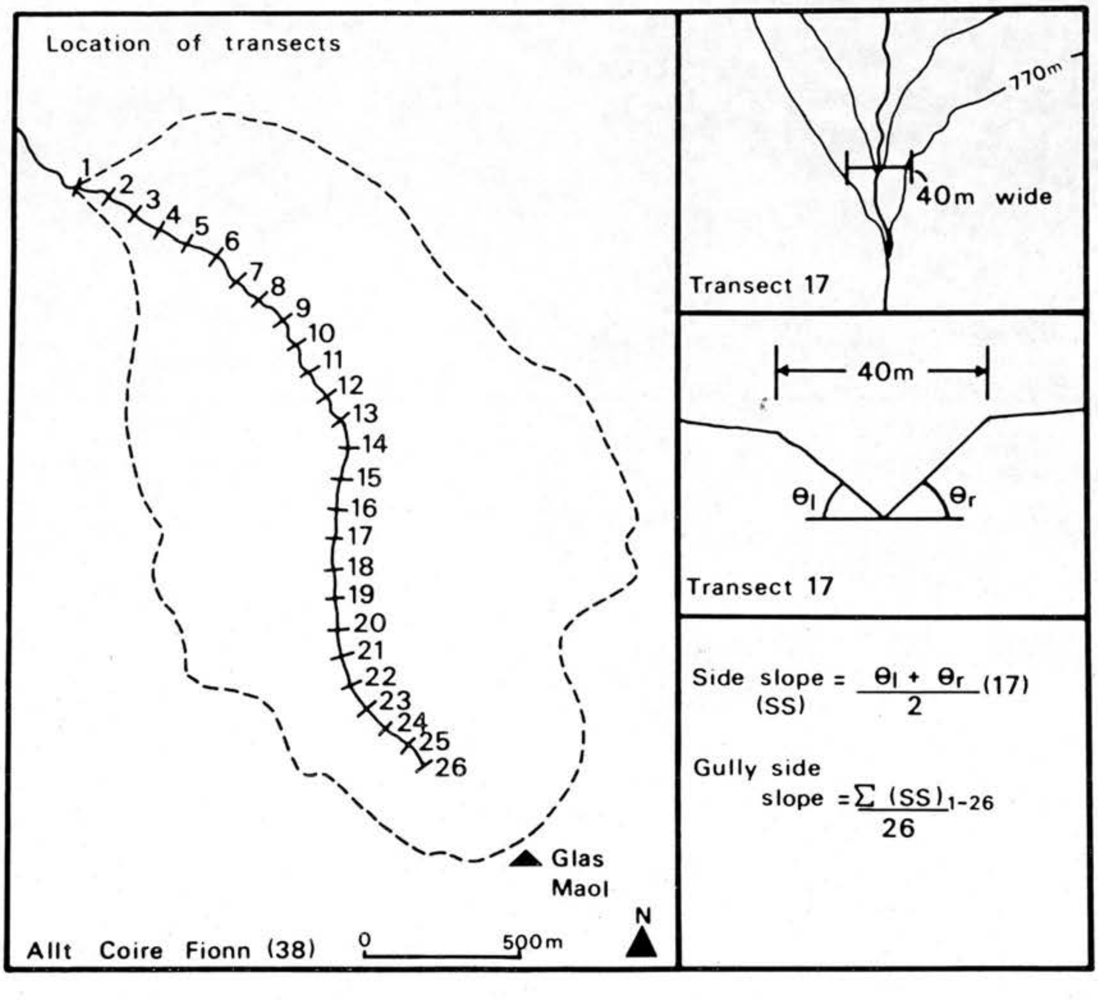


Figure 3.7: The measurement of gully side slope.

The depth of a gully was found to be closely correlated with the angle of the side slopes. For the 54 sites being studied, the Pearson product moment correlation coefficient between the two variables was 0.94. To avoid having very similar variables in the multivariate analysis (see section 6.2.1), gully depth was dropped. The assymetry of the side slopes of a gully may influence the entrapment of snow depending upon the direction of the wind. As summing the value of each transect tends to generalise the data (i.e., assymetry was often on alternate banks at different transects), the influence of assymetry on the drifting of snow would be studied better at each transect.

The incision of a basin can be measured by dividing the depth of a basin by its width, and can be called basin ratio. A low ratio means that the basin is shallow relative to its width, while a high ratio means the basin is deep and narrow. Figure 3.8 shows how basin ratio is measured. Form ratio (see Figure 3.8) measures the shape of a basin, being derived from the area of a basin divided by the square of its length, and is widely used in studies of basin morphology (Gregory and Walling, 1976). A site with a high ratio is wide relative to its length and may, therefore, create turbulence in the air within the basin. Large quantities of snow may be deposited, therefore, on steep headwalls rather than in the gully.

Topographic exposure is the subtend of the contour at the mid-point of the gully, as shown in Figure 3.8. A gully with a high value is essentially open and creates much less turbulence in the air than a site with a low value. A variable called

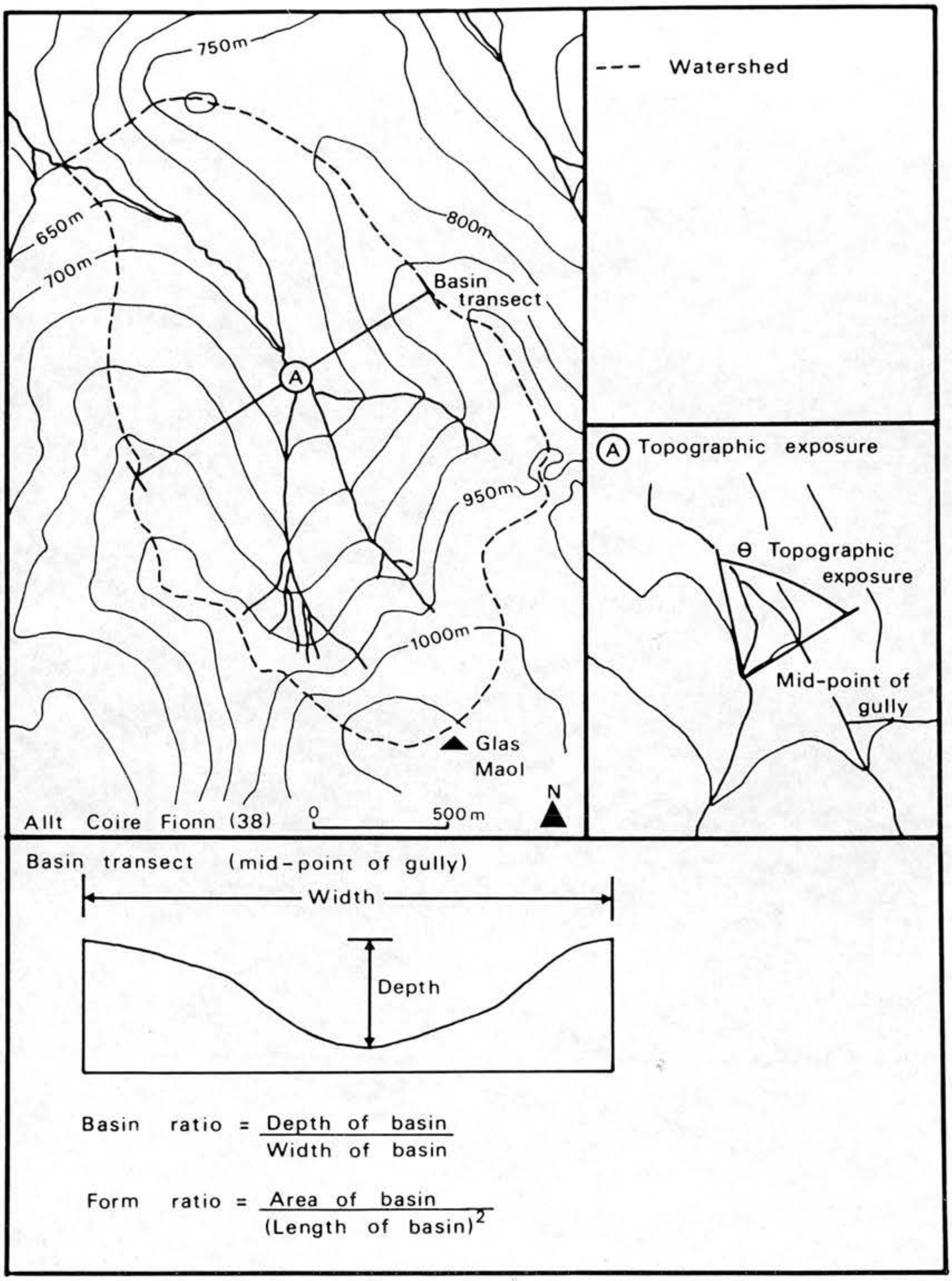


Figure 3.8: The measurement of the morphology of drainage basins.

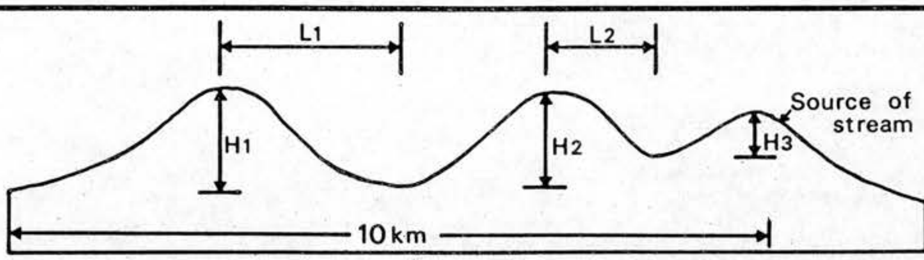
"topex" has long been used by foresters and is defined as the sum of the angles to the horizon measured from the site, and so measures the degree of exposure at the site in relation to surrounding terrain. Topographic exposure, as defined in this study, measures the degree of openness of the site and is more related, therefore, to the incision of the terain at the site.

The altitude of the source of the stream can be used to represent gradients of precipitation and temperature. A second variable, the length of a gully above 760m (or any other altitude), was dropped because within the criteria for identifying sites some sites are almost completely above 760m. Top altitude was assumed to be the most important indicator of the influence of altitude on the consistency of snowcover.

The amount of global radiation can be calculated for any site and day of the year. Computer programs are available for this which require data on the angle and aspect of the slope, the degrees of latitude and the day of the year (e.g., Williams et al., 1971; Dozier and Outcalt, 1979).

The upwind depletion of snow represents the increase in orographic precipitation with the forcing of air over massifs and the deposition of snow on leeward slopes upwind of a site. Rhea and Grant (1974) measured the topographic slope of the land for 20km upwind of a site, which was the product of the difference in altitude of a station and a point 20km distant. In the Eastern Highlands of Scotland, the total possible rise in altitude over 20km is not great. There appears to be a difference, however, between sites on the fringes of a massif and those within a massif. Storms must pass over intervening valleys and summits as they cross the massif which is likely to create large and possibly regional-scale turbulence. This may lead to depletion of snow and an increase in the amount of precipitation owing to orographic lift.

Figure 3.9 shows the morphology of the terrain upwind of a site. Topographic rise is the total rise of the terrain for 10km



Topographic rise (TR_{ene}) = H1 + H2 + H3 +.....+ Hn for each direction

Value for gully = $\frac{TR_{nne} + TR_{ene} + ... + TR_{nnw}}{8}$

Leeward slope (LS_{ene}) = L1 + L2 +......+ Ln for each direction

Value for gully = $\frac{LS_{nne} + LS_{ene} + ... + LS_{nnw}}{8}$

Figure 3.9: The measurement of the morphology of the terrain upwind of a site.

upwind of a site and measured for eight wind directions (NNE, ENE, etc.). Leeward slope is the extent of all leeward slopes for 10km upwind of a site and measured for eight wind directions.

The final process is the relative supply of snow. Fetch is a commonly used variable in the study of the drifting of snow but has rarely been used in regression studies or in more general studies of the distribution of snowcover. Fetch is defined as the length of relatively flat terrain upwind of the source of the stream from which snow can be blown onto the site. Fetch is measured for certain of the wind directions, e.g., NNE, ENE, etc.

Sutherland (1984, p.304) suggested the variable of "potential snow-blowing areas", defined as "...those slopes, within the catchment, that sloped directly on to the accumulation area or a potential avalanching area". This was measured for the four quadrants (NE,SE,SW,NW) for the sites of Loch Lomond Readvance glaciers by Sissons and Sutherland (1976) and Sissons (1979, 1980). Although being a useful attempt to incorporate the drifting of snow into studies of former glaciers, the variable is not appropriate to this study because snow is rarely blown across the land, apart from off ridges, at altitudes of less than 750m because of vegetation and lower wind speeds. The wind drifting of snow can be considered using the fetch and a variable called "wind-drift" (Ward, 1981).

Wind-drift is the percentage of the total amount of snow which would be blown onto a site on the basis of the frequency of wind directions during days with wind-drift and the direction of the fetch. The capacity of the wind to transport snow is related to its speed (Budd et al., 1966) and so the contribution of each day to total wind-drift can be calculated if the wind speed is known. Figure 3.10 shows how wind-drift is calculated.

If most snow is deposited on leeward slopes during snowfall then a relative figure of the supply of snow can be calculated if the wind direction is known. Figure 3.10 shows that snowdrift is the percentage of the total amount of snow which would be deposited at a site on the basis of the direction of the wind and the directions for which the site is leeward (Ward, 1981).

Eleven variables have been identified: gully side slope, basin ratio, form ratio, topographic exposure, altitude of the source of the gully, global radiation, topographic rise, leeward slope, fetch, snowdrift and wind-drift. Given further time in order to undertake field measurements this list could be extended to include gully width and apex angle. Field measurements of the drifting of snow over several winters may help to identify

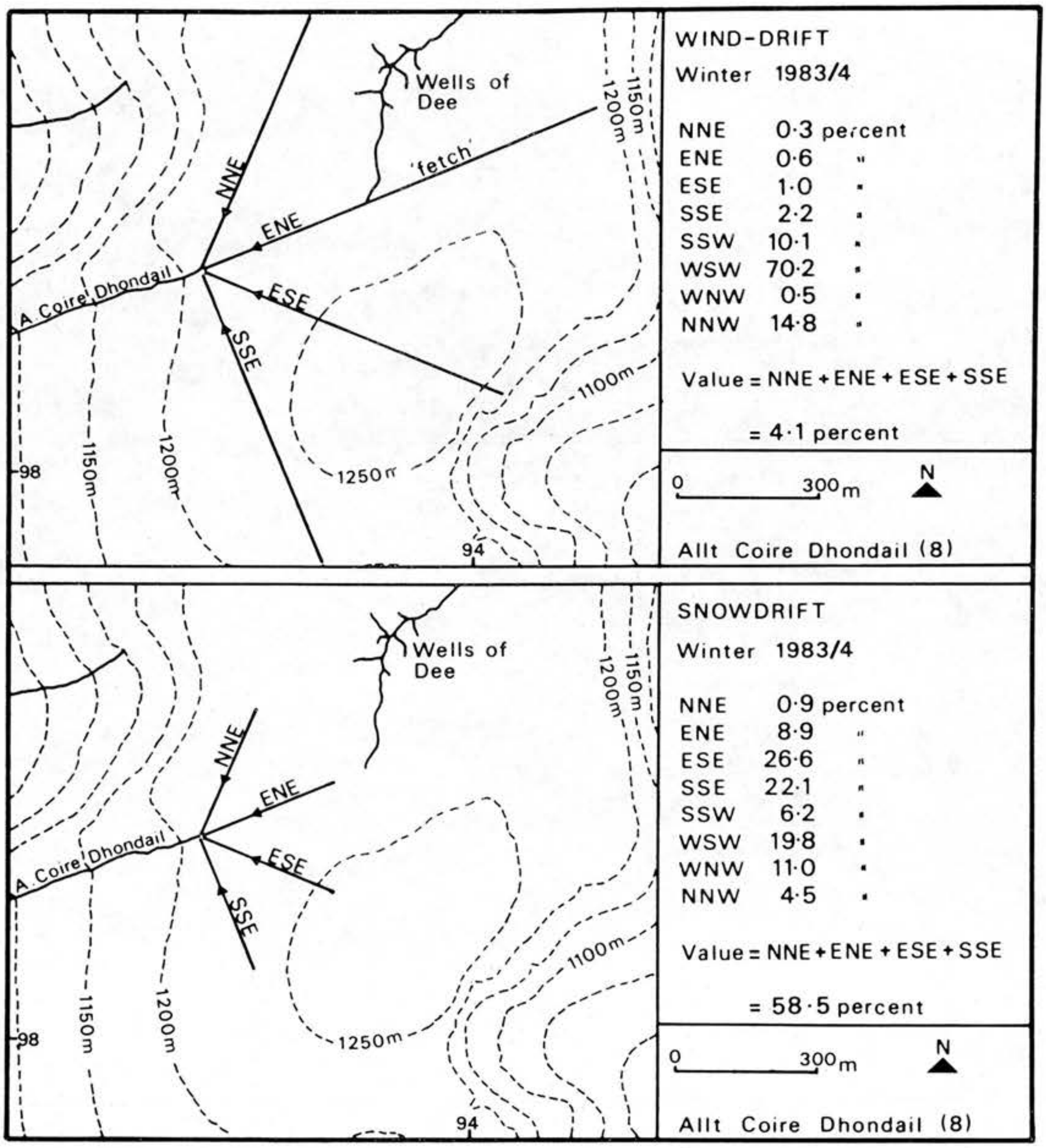


Figure 3.10: The measurement of snowdrift and wind-drift.

further variables and to test the relevance of those identified. It must be remembered, however, that changes in slope of nine degrees and small obstacles of less than one metre in height can induce the drifting of snow. A drainage basin contains many such features and hence only a few basins could be measured. The measurement and limitations of each variable are examined in Chapter 5.

3.5 A METHOD OF ANALYSIS.

3.5.1 Introduction

The first two steps in the procedure for identifying sites with the most consistent snowcover (see Table 2.6) have been accomplished in this chapter. The aims of this section are to review previous attempts to measure potential and to describe in detail the method to be used to measure the natural potential of sites for downhill skiing accurately (step five in Table 2.6).

3.5.2 A review of methods

The fifth step in the procedure is to translate the data into accurate measures of natural potential. A large number of methods were reviewed by Davison (1982b), but the main findings will be summarised here.

Most methods, including those concerned with agriculture and forestry, define potential as the suitability or capability of land for a given use (see Davidson, 1980, and Dent and Young, 1981 for reviews). The suitability of land for a given use is never usually defined (unless it is done implicitly), so a dependent variable is rarely identified to represent potential for use in validating the results. The first requirement of any method, therefore, must be a clear definition of potential which permits the identification of a dependent variable. Land capability for agriculture can be represented by the yield of the land under different crops (similarly for forestry). For land uses such as recreation, facilities for the disposal of waste and housing, a dependent variable cannot be identified easily to represent potential and in many cases is not. This is particularly true for downhill skiing (e.g., Canada Land Inventory, 1969; Duffield and Owen, 1970; Jubenville, 1976; Davison, 1981).

Most methods use an ordinal scale by which a site is given a certain score if it has a particular value. These scores are then summed and the sites classified or ranked. Examples include the Canada Land Inventory (1969), Vedenin and Miroshnichenko (1970), Jubenville (1976) and Davison (1981) for downhill skiing, and for agriculture and forestry (see Davidson, 1980 for a review) and for "urban" land uses (e.g., Miller and Carter, 1979; Anderson and Greenberg, 1981). The values for an ordinal scale are usually chosen subjectively and are rarely tested for validity. Their use also leads to a loss of information as they generalise the data: groups, rather than individual sites, are compared. The Canada Land Inventory (1969), for example, has three classes of sites for downhill skiing that include the following requirements:

CLASS ONE: vertical drop of between 500 feet and 1000 feet.
CLASS TWO: vertical drop of between 1000 feet and 2000 feet.
CLASS THREE: vertical drop of more than 2000 feet.

The exact relationship between these requirements and the potential of each site for downhill skiing was never explicitly stated or tested. A further problem is that if a site is allocated to class two, for example, its vertical drop could be as little as 1000 feet or as great as 1999 feet: information, therefore, is lost.

To measure potential accurately, any method must have a clear definition of potential and use, where possible, continuous scales of measurement. Elements of subjectivity, such as the choice of arbitrary scales, must be limited. Finally, the relationship between the variables and the definition of potential must be unambiguous and, where possible, tested for validity. The aim of the thesis does not incorporate the objective of comparing the results with those from the use of other methods (although this would be a logical avenue for future research). It rather allows the development of a method that can measure potential accurately. If this is achieved, the method can then be compared with other methods.

3.5.3 Method of analysis

Any attempt to measure the potential of sites for downhill skiing is likely to be constrained by five problems:

1. there are only three weather stations above 600m in the study area and records are short-term and fragmentary;
2. no additional measurements of wind speed and direction can be undertaken because of constraints of time and cost;
3. there are few data on the distribution, depth and density of snowcover in the study area;
4. there have been few studies of snowcover in environments that are as windy as the study area; and
5. there have been no regression studies of snowcover within the study area (or in the Scottish Highlands).

This chapter has so far identified five processes that control the consistency of snowcover and eleven variables to represent these processes. It can be hypothesised that the site(s) with the most favourable values on the variables should have the most consistent snowcover. A gully with steep side slopes, for example, should entrap more snow than a gully with gentler side slopes and should, therefore, have the most consistent snowcover (all other things being held constant). Snowcover should be less consistent at a site with high global radiation than at one with low global radiation (all other things held constant).

The assumption that all other variables can be held constant, however, is untenable. A site with steep gully side slopes, for example, may have a high value of global radiation, so that the advantages created by steep side slopes are negated by the high global radiation. The site with the most consistent snowcover, therefore, will have the most favourable combination of values on all of the variables measured.

The method of analysis must determine, therefore, if there are any relationships between the variables at the sites being studied. This is equivalent to testing the null hypothesis that each variable has an independent spatial distribution. The objective of the method is to identify combinations of variables that confer particular advantages or disadvantages on certain sites as to the consistency of snowcover. It should then be possible to determine that site A is better than site B. Assuming that each variable is of equal importance (there are no grounds to suppose otherwise), the extent to which a poor value on one variable is compensated for by a good value on another might be determined.

The problem, therefore, is a multivariate one. Three statistical methods - principal components analysis, cluster analysis and discriminant analysis - that have been widely used by geographers (e.g., Mather and Doornkamp, 1970; Mather, 1976; Unwin, 1977; Johnston, 1978), can be used to examine this problem. Their use in the evaluation of land, however, has been largely restricted to the study and classification of soils (Webster, 1977).

Principal components analysis transforms a set of variables to a new set by locating each new variable in vector space by its correlations with the original variables. As it is based on a matrix of correlation coefficients, the technique can be used to assess the null hypothesis that each variable has an independent spatial distribution, because it identifies groups of interrelated variables. Each site has a score on each component which reflects its values on the original variables and the loadings of the variables on the components. If a group of strongly related variables exists, it will then form the basis for the first component. Sites that are strongly related to this group will have very low or very high scores on the component that, if the component can be interpreted in a physical sense (i.e., its relationship to the consistency of snowcover), can be used as measures of natural potential (e.g., a high score may represent more consistent snowcover). The scores can be used in regression analyses, so their validity can be guaged by calculating how much variation in the extent of snowcover is accounted for by them.

Cluster analysis can be used to identify groups of sites with similar values on the variables measured. The method uses scores on the principal components as input so sites within a group should have similar potential. The classification can be tested using discriminant analysis, which finds the combination of the original variables that best discriminate between the classes. These combinations of variables, or functions, can be used to allocate new sites to their appropriate classes such that all sites within the study area can be classified. The component scores and classification functions should represent, therefore, differences in the consistency of snowcover at the sites.

Over the last ten years there have been calls for more research into the drifting of snow. Martinelli (1975) suggested there was a need to identify those combinations of terrain features that result in sites where the accumulation of snow is high. Radok (1977) suggested that the work of Tabler (1975) could be extended

> "...by means of sequences of aerial photographs taken during the melt season. Such photographs would show the most persistent drift accumulation which could then be systematically analysed in terms of mapped topographical parameters and weather records for the preceding accumulation season" (p.132).

Progress in fulfilling these calls, however, has been slow, although research by Berg (1977), Fohn (1980), Fohn and Meister (1983), Daly (1984) and Minnich (1984) has helped to improve knowledge of the processes involved. To present meaningful results for the aim of this research, i.e., to measure the natural potential of sites for downhill skiing, using the relationships between land morphology and the processes in Figure 3.5, the research must attempt to make progress in understanding the influence of the processes on the consistency of snowcover and to measure this influence.

In mountain areas where there is a dominant wind direction (e.g., Rocky Mountains, European Alps), windward and leeward slopes can be easily identified. Kuz'min (1963) noted that the distribution of snow is most pronounced when winds blow throughout the winter from a more or less constant direction. A similar regularity is not observed in the case of winds with variable directions. To aid in the interpretation of results it will be necessary, therefore, to determine the frequency of wind directions in the study area. An attempt will be made in Chapter Four to provide a consistent database on winter weather and on the relative supply of snow so that objective statements on weather can be made. A thirty year period should be used to cover and short-term variability in the supply of snow (Goodison et al. 1981).

3.5 CONCLUSIONS

1. Mountain areas with similar wind speeds to those recorded in the Scottish Highlands include the ridges and summits of the Rocky Mountains, the coastal mountains of North America, the High Arctic and inland regions of Antarctica.

2. The review of literature identified five processes that control the consistency of snowcover: the creation of turbulence in the air, gradients of precipitation and temperature, the relative supply of snow, global radiation and the upwind depletion of precipitation.

3. Regression studies of snowcover have not included all of these processes in a sinlge study.

4. The dependent variable is the extent of snowcover in a gully expressed as a percentage of the length of that gully.

5. Eleven variables were identified to represent the five

processes which control the consistency of snowcover: gully side slope, basin ratio, form ratio, topographic exposure, top altitude, global radiation, topographic rise, leeward slope, fetch, wind-drift and snowdrift.

6. The objective of the method of analysis is to identify combinations of variables that confer particular advantages or disadvantages on certain sites as to the consistency of snowcover.

7. The method will use principal components analysis to identify these relationships. The scores on the components will be interpreted as measures of natural potential.

The measurement of the variables is discussed in Chapter 5. The natural potential of sites for downhill skiing is measured in Chapter 6 using multivariate statistics. The validity of these measures is examined in Chapters 7 and 8. The next chapter presents a verifiable database on winter weather over the period 1954/5 to 1983/4.

CHAPTER 4: WINTER WEATHER AND THE SUPPLY OF SNOW: 1954/5 TO 1983/4.

4.1 INTRODUCTION

The aim of this chapter is to create a consistent and verifiable database on weather during 30 winters from 1954/5 to 1983/4. The database will have three main uses:

1. to provide relative data on the supply of snow to sites within the study area (see Chapter 3);
2. to provide consistent and objective statements on winter weather within the study area, and
3. to determine if the seasons used in the validation of results are representative of long-term patterns of the supply of snow (see Chapter 7).

In the chapter, existing sources of data are reviewed and a method for the collection and analysis of data outlined. The measurement of the supply of snow to sites within the study area is described and the results assessed. Although a large amount of data is presented in Appendices 2 to 6, the analysis is restricted to that necessary to meet the objectives of the research.

4.2 EXISTING SOURCES OF DATA AND METHOD OF ANALYSIS

4.2.1 Existing sources of data

Since 1954/5, eleven manned weather stations have operated at some time within or near the study area. There have also been seven automatic weather stations (AWS), of which six are still in operation. Table 4.1 lists the altitude of each station, its period of operation and present operational status. Figure 4.1

Table 4.1: Weather stations in or near the study area. Y = operational, N = not operational.

	Altitude	Period of records	Status
Manned			
ACHNAGOICHAN	305m	1959/0-1969/0 1973/4-1978/9	N
AVIEMORE	235m	1982/3-1983/4	Y
BALMORAL	283m	1954/5-1983/4	Y
BLAIR ATHOLL	122m	1962/3-1983/4	Y
BRAEMAR	339m	1954/5-1983/4	Y
DALWHINNIE	362m	1954/5-1959/0 1973/4-1983/4	Y
GLENMORE LODGE	341m	1954/5-1979/0	N
GLENSHEE LODGE	321m	1956/7-1965/6	N
GRANTOWN ON SPEY	229m	1957/8-1983/4	Y
KINDROGAN	259m	1972/3-1983/4	Y
LAGGANLIA	259m	1975/6-1983/4	Y
Automatic			
CAIRN GORM	1245m	1978/9-1983/4	Y
CISTE MHEARAD	1075m	1982/3-1983/4	Y
COIRE CAS	760m	1982/3-1983/4	Y
GLENMORE LODGE	341m	1982/3-1983/4	Y
MORRONE	867m	1980/1-1981/2	N
PTARMIGAN	1087m	1963/4-1983/4	Y
QUEENS FOREST	335m	1982/3-1983/4	Y

shows the location of each station. Although ten weather stations are located to the north and west of Cairn Gorm (see Figure 4.1), their records are, at present, too few for a temperature lapse rate to be calculated accurately. Future research, however, may take advantage of more records as they become available. There are few observations, and none for land above 400m, for the remainder of the study area. An automatic weather station operated between the summers of 1980 and 1981 on the summit of Morrone (867m), but no permanent records were kept by the operators, the Institute for Offshore Medicine of the University of Aberdeen (Norman, pers. comm.).

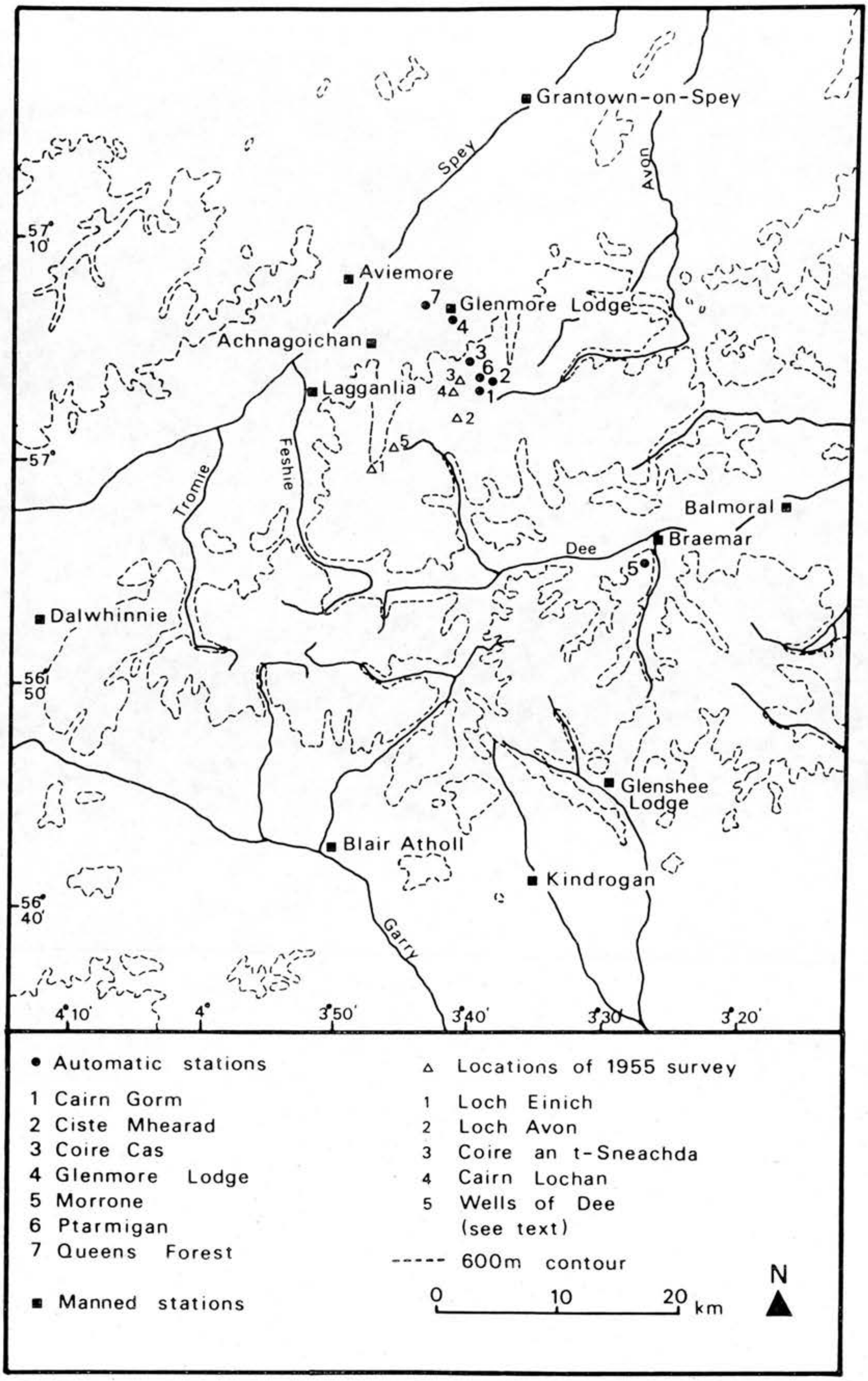


Figure 4.1: Location of weather stations within or near the study area.

Stations operated by observers for the Meteorological Office record, amongst other things: daily maximum, minimum and mean air temperatures; wind speed and direction, and the amount and type of precipitation. When precipitation falls as snow, a water equivalent value is derived using the procedure outlined in the Observer's Handbook (Meteorological Office, 1962).

The automatic weather stations (AWS) are mostly recent and their records, particularly in winter, are infrequent due to the riming of instruments and the harsh environment (Borthwick, 1983). The Ptarmigan AWS records wind direction and speed, while the remaining stations (with the exception of Cairn Gorm where solar radiation is not recorded) records wind speed and direction, maximum and minimum air temperatures and solar radiation. Records from the AWS operated by Heriot-Watt University on the summit of Cairn Gorm have been published by the University (1983). These records show that mean monthly windspeeds during winter can reach 24.5 m/s (Barton, 1984) and that the mean speed for the winter months is 15.1m/s (see Table 3.1). The Ptarmigan station began operation in 1964 but records for the winter months are infrequent, for reasons noted earlier. Both stations have locational disadvantages: the Ptarmigan site is sheltered from SE winds, while the Cairn Gorm station is located on a rounded summit where wind speeds can be artificially high (Borthwick, 1983; see Plate 1 in Chapter 3).

No data for snowfall or precipitation have been collected above 400m. The only records of precipitation available are those for Meteorological Office stations, which are all located at low altitude.

Several studies of climate have been undertaken within the study area. Champion (1950) measured the rate of melt of a snowpatch near Ben Macdui in July 1949. Over a period of 18 days, 63.9 inches of melt occurred. Dybeck and Green (1955) recorded air temperature and rainfall at five locations (Loch Einich, Loch Avon, Coire an t-Sneachda, Cairn Lochan and the Wells of Dee: see Figure 4.1) during the period 31.7.53 to 15.8.53. A temperature lapse rate of 0.8^0C and a gradient of precipitation of 22.5mm for every 100m rise in altitude were calculated. The gradient of precipitation is considerably lower than those recorded in the NW Highlands by Ballantyne (1983).

McVean (1958) measured the depth of snow at eleven locations on Ben Macdui, Geal Charn and Carn a' Mhaim during the winters of 1955/6 and 1956/7. He found that the pattern of vegetation was closely related to the duration of snowcover. These findings were confirmed by a second study (McVean, 1963) of the accumulation and melting of snow near Cairn Gorm. Wind speed was recorded on the slopes of Creag an Leth-choin during the period March 1961 to March 1963 by Pears (1964), using tatter flags. Although the rate of increase in the tatter rates decreased with altitude, the tatter rate at 880m was eleven times that for a site at 381m.

Morris (1982, 1983) and Ferguson (1984) have produced models of snowmelt for two locations in the Cairngorm Mountains. Morris tested three models of snowmelt for a site in Coire Cas (650m). Data on precipitation, temperature, humidity, radiation and wind speed and direction were collected using an AWS. A rate of melt of 2.0mm + 0.8mm per day ^{0}C was calculated over a period of 12 days in February and March 1979. The aerodynamic roughness of the surface of the snow and turbulent exchange were found to be important. Ferguson was able to predict daily discharge in the River Feshie using daily air temperature and precipitation recorded at Lagganlia. A coefficient of determination of 0.88 over 53 days in April and May, 1979 was calculated. The individual components of melt (radiation, turbulent exchange, etc.), however, were not examined.

Ward (1981) measured the relative supply of snow to sites where there was a high risk of avalanching for the winters of 1977/8 to 1979/80. Data on wind speed and direction and temperature at Glenmore Lodge, Lagganlia, Ptarmigan and Cairn Gorm were used. Ward predicted a wide variety of avalanche types on a total of 56 days. The procedure used by Ward to measure the supply of snow is that used in this study (4.2.2).

These studies were all site specific and ephemeral, and in most cases the period of observation was short. Few attempts were made by the authors to place their work and results in a wider spatial and temporal context, owing to the absence of long-term data and more frequent studies of climate.

There are no consistent observations, therefore, of wind speed and direction, precipitation or temperature for land above 400m within the study area. Extrapolation of data on temperature is possible using known lapse rates, but impossible for precipitation owing to the paucity of data. The need to obtain data on wind speed and direction can be solved, to a limited extent, by measuring the free airflow or geostrophic wind (Vg) from the daily weather charts published by the Meteorological

Office (McIntosh and Thom, 1981). If the Vg is measured at sea-level pressure it will be roughly equivalent to actual surface wind speeds at an altitude of 1000m over land (Roy, pers. comm.), so consistent data on wind speed and direction over a long period of time can be created.

4.2.2 Method of analysis

The procedure by which the database on winter weather is created and the supply of snow measured is shown in Figure 4.2. In the Scottish Highlands, snowfall is nearly always accompanied by wind (Ward, 1981). Snow is deposited, therefore, on leeward slopes as described in section 3.2. This component of the supply of snow can be called "snowdrift" (Ward, 1981). "Wind-drift" is the transport of previously deposited snow by the wind.

Snowdrift occurs on days when precipitation falls as snow. Only days with more than 1.0mm of precipitation are used in the measurement of snowdrift. Wind-drift occurs on a particular day when:

1. that day is within two days of a day with snowdrift;
2. temperatures have not risen above 0^{0}C between the last day with snowdrift and the day in question; and
3. the wind speed is more than 10m/s.

For both snowdrift and wind-drift, relative amounts are calculated on the basis of wind direction. Full definitions are given in sections 4.5.1 and 4.6.1. To calculate snowdrift and wind-drift, data are required on the amount and type of precipitation (which requires data on temperature) and wind speed and direction.

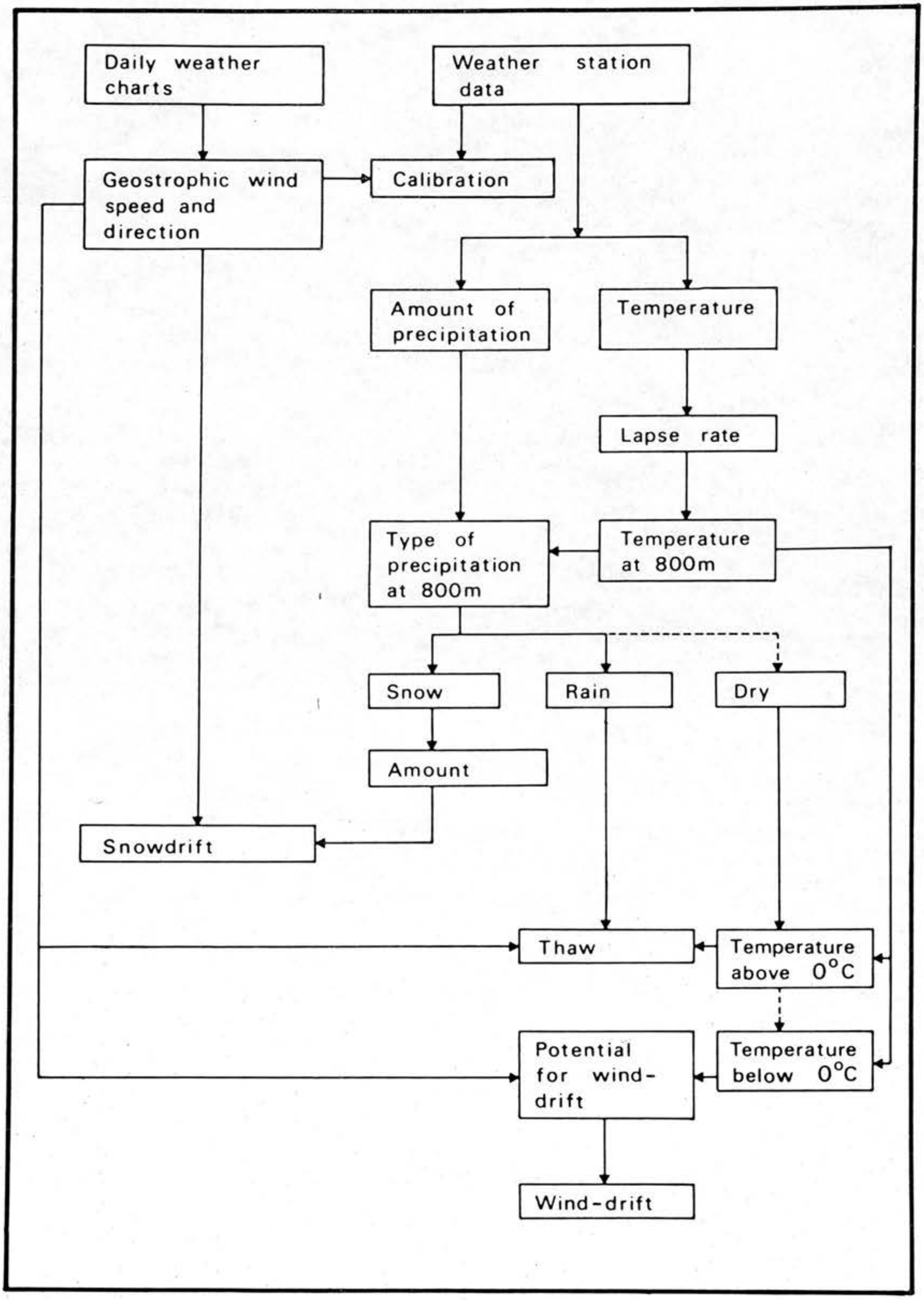


Figure 4.2: Procedure for the measurement of the supply of snow.

The geostrophic wind speed and direction is calibrated against surface wind data from the AWS on the summit of Cairn Gorm. Data on precipitation and temperature are taken from the daily returns for the stations at Achnagoichan (1964/5, 1966/7, 1967/8), Braemar (1954/5 - 1983/4), Glenmore Lodge (1954/5 - 1963/4, 1965/6, 1968/9 - 1970/1) and Lagganlia (1971/2 - 1983/4). A lapse rate is applied to the temperature at station level to determine if precipitation was falling as snow or rain at approximately 800m (the middle altitude of many sites).

4.3 WIND SPEED AND DIRECTION

4.3.1 Measurement of geostrophic wind (Vg)

The Vg is proportional to the distance between the isobars drawn on the daily weather charts (McIntosh and Thom, 1981). Figure 4.3 shows that the Vg is a product of the pressure force,

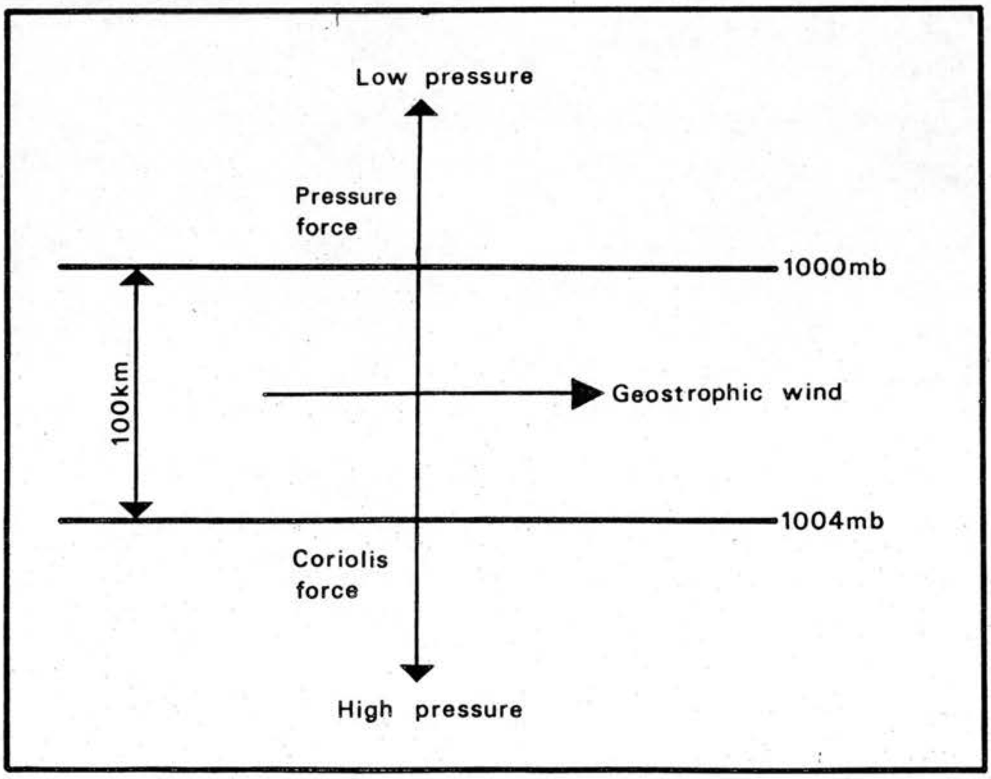


Figure 4.3: Measurement of the geostrophic wind speed.

which exists between areas of low and high pressure, and the Coriolis force, which is created by the rotation of the Earth.

The Vg is calculated from the equation:

$$Vg = \frac{1}{fp} \times \frac{dp}{dn}$$

where f is the Coriolis force (derived from the angular velocity of the Earth and the latitude of the site), p is the density of air and dp/dn the pressure force (derived from the distance between the isobars). The following example (based on Figure 4.3) shows how the Vg speed is calculated:

$$\frac{dp}{dn} = \frac{4}{100}\ \text{mb/km} = \frac{4 \times 100}{100 \times 1000}\ \text{S.I. Units}$$

if latitude is 57^0N, then $f = 2\Omega \sin \phi = 0.000122$/second (where Ω = Earth's angular velocity = 0.0000729 (rad)/s);
if the density of air is 1.21 kg/m^3 (McIntosh and Thom, 1981), then

$$Vg = \frac{0.004}{0.000122 \times 1.21} = 27.1\ \text{m/s}.$$

The measurement of the Vg from the weather charts is made easier by using a "geostrophic wind scale". The scales used in this thesis were drawn on clear plastic and graduated in metres per second (m/s). Several scales were required because maps of different scales were used. The scales were calculated using the following assumptions: latitude = 57^0N, density of air = 1.21 kg/m^3, and air pressure = 1000mb (sea level). A value for the density of air of 1.21 kg/m^3 was used because this is the average value at sea-level (McIntosh and Thom, 1981). The Vg was measured from two charts only on each day (0000 hours and 1200 hours) owing to constraints of time, although checks were made to determine if the data were representative of values derived from four charts. The values were similar enough to allow the use of two charts only. The influence of temperature on the density of air and so on the calculation of the Vg speed is examined in section 4.3.2.

The direction of the Vg was estimated from the orientation of the isobars and directions of surface winds marked on the charts. The main problem was to derive a mean direction for each date from two charts. The direction used was that where the two values were identical or, where there was equal division, the one with the highest speed. In the latter case, it was assumed that the higher wind speeds would produce larger amounts of drifting so the wind direction associated with these higher speeds would be more important.

A comparison between the resultant directions and those of Lamb (1972), who compiled a register of the daily sequence of weather patterns for the period 1861 to 1971, confirmed that the directions were almost identical. The mean Vg speed and direction for each of the 4538 days in winters between 1954/5 and 1983/4 are listed in Appendix 2 and will be analysed later.

4.3.2 Sensitivity analysis

A sensitivity analysis was undertaken in order to assess the accuracy of the data. There were two sources of error: the density of air and the gradient wind force. A representative value for the density of air close to sea level is calculated using the equation $p = P/RT$ (McIntosh and Thom, 1981),
where $P = 10\ N/m^2$;

$$R = \frac{\text{gas constant}}{\text{weight of dry air}} = \frac{0.08314}{29.0} = 0.0287$$

$$T = 288^0K$$

$$\text{therefore } p = \frac{10}{0.0287 \times 288} = 1.21 \text{ kg/m}^3$$

If the air temperature, however, is 0^0C (273^0K), then p becomes 1.28 kg/m^3 and the Vg speed, in the above example (Figure 4.3), is 25.6m/s. This is a reduction of 1.5 m/s (5.5%) for an isobar spacing of 100 km. If the "actual" density of air was to be used, then the Vg would need to be calculated on a day-by-day basis, a considerable undertaking for 4538 days. The potential inaccuracy of 0.37% per ^0C was accepted. The values of Vg in winter, therefore, are likely to be consistent, but slight, overestimates.

The calculation of Vg assumes that the isobars are straight and parallel. In most situations the isobars are curved producing either anticyclonic flow which reduces the Vg speed, or cyclonic flow which increases it (McIntosh and Thom, 1981). Owing to the increase in workload required for the calculation of gradient wind flow (i.e., the Vg speed would need to be calculated for each day) it was excluded from this study. This omission will result in over-prediction of the speed during cold, anticyclonic weather and under prediction for cyclonic weather. To some extent this inaccuracy is mitigated by the classification of wind speed for the measurement of snowdrift (see section 4.5.1).

4.3.3 Calibration of the Vg with surface wind data

The Vg speed was measured at sea level pressure on the assumption that this would be equivalent to wind speeds over land at an altitude of approximately 1000m. The Vg speed should correlate well, therefore, with speeds recorded at the AWS on the summit of Cairn Gorm (1245m). Pearson's product moment correlation coefficient was used to test the null hypothesis that variations in the speed of the Vg and surface winds were not correlated. Five sets of data, distributed normally about the mean, covering 382 days were used. Table 4.2 shows the mean and standard deviation for each set of data. The mean wind speeds for the five sets of data are very similar, although there is a tendency for the standard deviations of the surface winds at the HW station to be greater than those for the Vg. Table 4.3 shows that the null hypothesis can be rejected for all five cases at the p = 0.01 level and at the p = 0.001 level for four cases.

Table 4.2: Mean and standard deviations of the Vg and surface winds recorded at the Heriot-Watt (HW) station on Cairn Gorm. N is the number of days.

Time period	N	Mean Vg	Mean HW	σ Vg	σ HW
DEC. 1978 - APRIL 1979	60	13.1	14.2	5.4	6.7
DEC. 1979	30	14.7	14.6	6.2	5.9
JAN. 1980 - MARCH 1980	59	13.7	13.2	5.0	5.8
DEC. 1980 - MARCH 1981	86	17.1	17.4	5.9	6.7
DEC. 1982 - MARCH 1983	100	17.8	16.4	6.8	7.7

Table 4.3: Correlation coefficients between the speed of the Vg and those recorded at Cairn Gorm. N is the number of days, r the correlation coefficient and p the level of significance.

Time period	N	r	p
DEC. 1978 - APRIL 1979	60	0.65	0.001
DEC. 1979	30	0.52	0.01
JAN. 1980 - MARCH 1980	59	0.69	0.001
DEC. 1980 - MARCH 1981	86	0.72	0.001
DEC. 1982 - MARCH 1983	100	0.66	0.001

Although the results are statistically significant, a correlation of 0.66 means that only 44% of the variation in wind speeds on Cairn Gorm can be accounted for by variation in the Vg. The results are very similar, however, to those for sites in West Germany studied by Wahl (1966). Wahl (p.15) found correlations of up to 0.75 between the speed of surface winds and that for the free air, and concluded that the "...wind speed on top of a mountain is most highly correlated to the wind speed in the free atmosphere at the same height, certainly stronger than to corresponding wind speeds at lower elevations".

The speed of surface winds on Cairn Gorm are often considerably higher or lower than the speed of the corresponding Vg because the gradient wind force was omitted in its calculation and a single value for the density of air used (see section 4.3.2). The rounded form of the summit of Cairn Gorm (see Plate 1) and the influence of temperature inversions above the summit, may also induce acceleration of airflow (Borthwick, 1983).

Although many authors have studied the nature of airflow across massifs, most work has been theoretical rather than applied (Barry, 1981). One exception is Pedgeley (1971), who arranged for 86 people resident in Snowdonia to measure wind speed and direction during February, 1971. Within the valleys, wind directions were often completely the opposite to the free airflow across the massif. With many valleys, high plateaux and corries within the study area, the wind speed and direction for any point will probably differ from the Vg speed and direction. The initial aim, however, was to gain a general picture of wind speed and direction within the study area.

4.3.4 Analysis of results

The mean Vg speed and direction for each day are listed in Appendix 2. The mean monthly speeds are listed in Appendix 3 together with data on precipitation, temperature and snowdrift. Table 4.4 shows the mean annual data for these variables.

Table 4.4: Annual summary of winter weather 1954/5 to 1983/4.

	Mean wind speed m/s	Mean ppt. mm	Mean max. temp. ^0C	Mean min. temp. ^0C	Snow drift	% PPT. snow
1954/5	14.8	388.8	4.9	-2.0	425	72.9
1955/6	14.0	408.0	3.9	-1.0	360	64.9
1956/7	15.0	411.7	7.3	0.5	232	42.9
1957/8	15.1	373.7	4.9	-2.1	386	83.3
1958/9	13.9	310.9	6.1	-1.7	259	66.7
1959/60	14.5	435.6	5.8	-1.1	393	69.9
1960/1	14.8	287.7	6.9	-0.5	243	60.1
1961/2	15.0	472.1	5.0	-2.7	494	90.9
1962/3	14.5	373.4	4.5	-3.4	300	62.3
1963/4	14.1	208.3	6.1	-0.3	153	50.6
1964/5	13.1	312.5	5.5	-1.9	307	67.6
1965/6	14.2	271.7	4.8	-1.6	245	62.4
1966/7	16.5	513.6	6.2	0.0	500	70.6
1967/8	12.9	320.6	5.8	-1.3	266	71.2
1968/9	14.0	361.4	4.7	-2.7	385	91.7
1969/70	14.0	375.5	4.3	-2.7	405	87.5
1970/1	11.6	260.5	6.7	-0.5	166	57.5
1971/2	14.5	381.1	6.8	0.2	362	70.3
1972/3	15.7	272.8	6.4	-1.0	321	82.3
1973/4	15.0	458.7	7.4	-0.9	516	83.4
1974/5	15.3	423.4	7.0	-0.3	347	59.8
1975/6	13.6	256.3	7.4	-0.3	252	72.7
1976/7	14.4	327.0	4.7	-1.9	319	69.6
1977/8	13.1	354.2	5.3	-2.2	338	76.8
1978/9	14.8	398.4	3.8	-3.1	462	84.5
1979/80	13.8	340.9	5.9	-1.1	335	79.6
1980/1	15.7	279.2	6.8	-0.8	266	69.6
1981/2	17.2	311.6	5.4	-2.1	457	91.8
1982/3	17.2	440.4	5.4	-1.2	498	77.3
1983/4	17.0	513.6	5.9	-1.4	643	84.6
MEAN	14.6	361.5	5.7	-1.4	355	73.3
S.D.	1.3	76.3	1.0	1.0	110	11.9

The mean Vg speed for all 4538 days is 14.6 m/s, with a mean of 16.1 m/s for days in December and 11.8 m/s for days in April. The highest mean monthly wind speed was 24.5m/s in January, 1983. Figure 4.4 shows the distribution of wind speed in classes of 5 m/s. The data have an approximately normal distribution, an interesting result in itself because most data on wind speeds are positively skewed (Wahl, 1966). This finding is indicative of the greater incidence of high Vg speeds over the Scottish Highlands as compared with other European locations (Wahl, 1966).

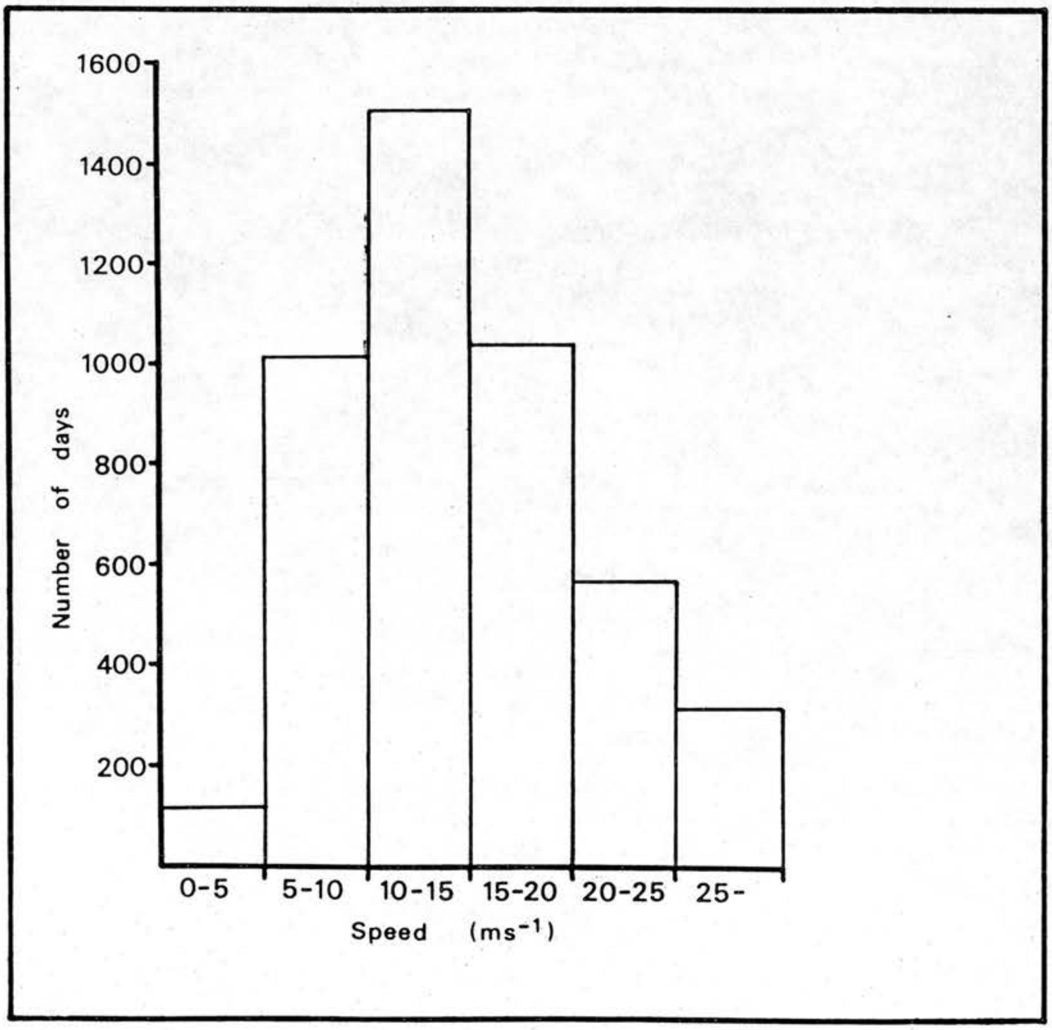


Figure 4.4: Distribution of the geostrophic wind speed.

Some 75.2% of all days had a mean Vg speed of more than 10 m/s, on 42% it was more than 15 m/s, on 19.2% more than 20 m/s and on 6.7% more than 25 m/s. These results can be compared with data on surface wind speeds recorded in other mountain areas of the world listed in Table 3.1.

In most mountain areas, particularly the European Alps (Meiman et al., 1971; Nägeli, 1971) and the Rocky Mountains (Ives and Fahey, 1971; Storr, 1973; Glidden, 1982), there is usually a dominant wind direction. There is no dominant direction for the Vg over the Scottish Highlands. Figure 4.5 shows the frequency of eight wind directions (NNE,ENE,...,NNW), the most frequent of

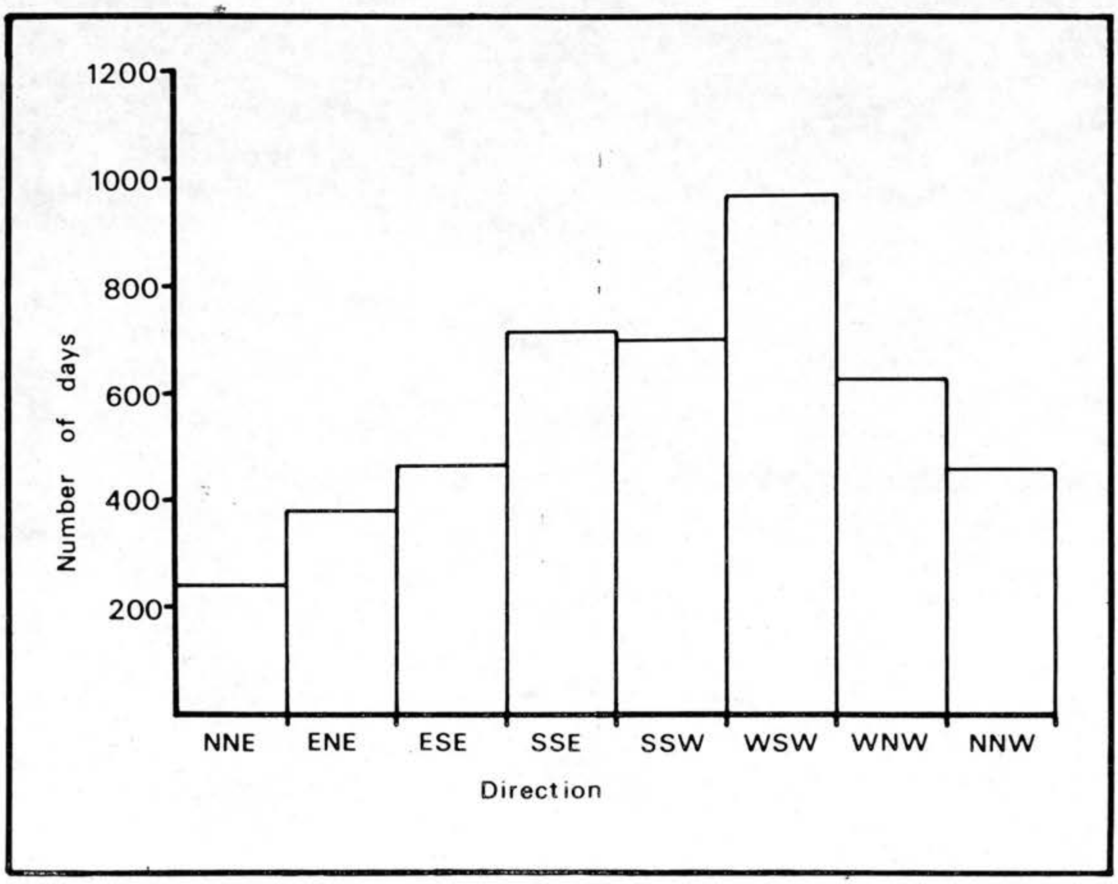


Figure 4.5: Distribution of the geostrophic wind by direction.

which are WSW (21.3%) and SSE (15.7%). Frequencies for the four quadrants are: NE (13.6%), SE (25.9%), SW (36.7%) and NW (23.7%). Although winds are most frequent from the SW, over 50% of all days have winds from the SE or NW. This has two important implications for the measurement of natural potential. First, few sites will be leeward for most of the time, and second, the influence of wind speed and direction on the distribution and depth of snowcover is likely to be considerable.

Figure 4.6 shows the frequency of wind speeds for each of the eight directions. The frequency of wind speeds below 10m/s is similar for all wind directions. Wind speeds of more than 15m/s, however, are more frequent with westerly winds, especially winds from the WSW.

4.4 TEMPERATURE AND PRECIPITATION

4.4.1 Collection of data

To calculate snowdrift, the amount and type of precipitation must be measured. Data on temperature is required to determine if the precipitation fell as rain or snow at an altitude of approximately 800m. Data collected at the stations at Braemar (1954/5-1983/4), Glenmore Lodge (1954/5-1963/4, 1965/6, 1968/9-1970/1), Achnagoichan (1964/5, 1966/7, 1967/8) and Lagganlia (1971/2-1983/4) were used. An average between the values for Braemar and one of the other three stations, for the periods stated above, was used to avoid the possibility of errors of measurement at either station and to accommodate changes in the amount of precipitation as frontal systems moved across the study area.

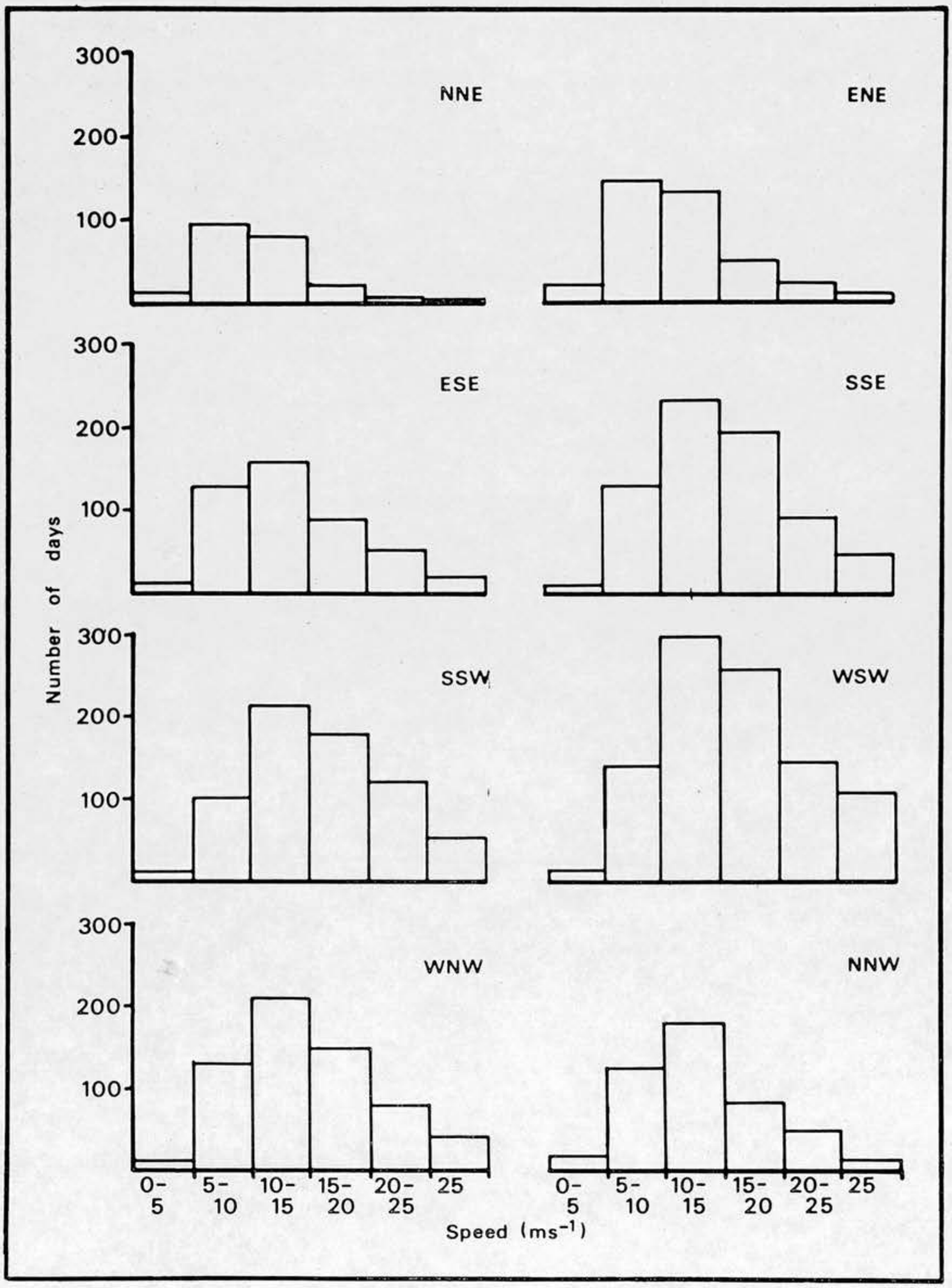


Figure 4.6: Distribution of the geostrophic wind by speed and direction.

The use of data for low altitudes means that temperature is overpredicted for altitudes above 400m, so a lapse rate must be applied to counter this. Although precipitation increases with altitude (Ballantyne, 1983), there are few data available by which this increase can be quantified, so the data for low altitudes must be used.

The probability of precipitation falling as snow is highest when the maximum air temperature falls below 2^0C (Manley, 1969; Ward, 1981). Ward calculated that 90% of all precipitation falls as snow below this temperature. When the maximum air temperature rises above 7^0C, 90% of all precipitation falls as rain. With a lapse rate of 7^0C per 1000m (a compromise between the lapse rate of 6^0C in winter and the 8^0C in Spring (Barry, 1981)), the temperature required at station level (the mean value between those for Braemar and one other station) for a probability of 90% that precipitation will fall as snow at 800m are:

1. when minimum temperatures fall below -10.5^0C
2. when maximum temperatures fall below $+ 5.5^0$C

and to fall as rain are:

1. when minimum temperatures rise above $+ 5.5^0$C
2. when maximum temperatures rise above $+10.5^0$C.

When calculating the type of precipitation for each day, reference was made regularly to notes on the weather submitted by the observer at Lagganlia with his monthly returns. The observer noted when precipitation fell as rain at station level and as snow at higher altitudes. Verification of the results is possible from four sources:

1. records from the Ben Nevis Observatory which operated from 1883-1904 (see below).

2. years with a high percentage of snow should be generally regarded in the literature as "snowy" (see below).

3. altitude of the snowline (fluctuations in the snowline would indicate precipitation falling as rain or snow); and

4. fieldwork notes for the winters of 1982/3 and 1983/4.

December 1983, is an excellent month to use for verification because there was a succession of cold and warm periods, with only 48.3% of the total precipitation of 149.4mm falling as snow. Table 4.5 shows the type of weather and the altitude of the snowline on Cairn Gorm and Ben Avon for that month. The weather predicted from the 1st to the 8th appears largely correct, although snow must have fallen overnight on the 6th/7th to lower the snowline on Cairn Gorm from 1200m to 750m. Rain on the 13th pushed the snowline higher at both locations on the 13th, 14th and 15th. Although the snowline on Ben Avon rose to 900m on the 17th, snow was predicted for an altitude of 800m. This may have fallen as sleet. The snow which fell between the 18th and 24th kept the snowline at 600m - 750m, but fell as rain below this. This may have fallen as rain at Cairn Gorm as the snowline there rose from 600m to 750m. Rain was predicted correctly for the remainder of the month, although snow fell during the night of the 29th. This snow was very light at all altitudes and melted on the 30th. The weather predicted for December was quite accurate, with only minor discrepancies on the 6th, 16th, 17th and 30th. All major snowdrift events were correct for 1983/4 (fieldwork notes). There are four minor sources of error, therefore, in the

Table 4.5: Winter weather and elevation of the snowline, December 1983. Elevation of the snowline in metres.

Date	Snow-drift			Cairn Gorm	Ben Avon	Date	Snow-drift			Cairn Gorm	Ben Avon
1	*			750	-	17	1	5	5	1050	900
2	*			NS	-	18	2	5	10	750	300
3	*			NS	-	19	3	5	15	750	600
4	RAIN			NS	-	20	3	5	15	-	600
5	-*-			NS	-	21	2	5	10	-	600
6	*			1200	-	22	1	4	4	NS	750
7	-*-			750	-	23	1	4	4	600	600
8	RAIN			1050	-	24	3	5	15	750	300
9	1	6	6	1200	300	25	--*--			750	600
10	--*--			300	300	26	RAIN			1050	750
11	1	4	4	300	300	27	RAIN			NS	900
12	--*--			300	300	28	*			NS	1050
13	RAIN			600	300	29	RAIN			NS	-
14	--*--			1050	600	30	RAIN			300	-
15	1	5	5	1050	750	31	RAIN			NS	-
16	1	4	4	1050	750						

Snowdrift: see section 4.5
--*-- : wind-drift
-*- : cold, dry day
* : warm, dry
RAIN : rain

prediction of winter weather from low altitude data:

1. snow falling at night but then turning to rain (e.g., 29th/30th);

2. snow falling in one area and rain in another (e.g., 24th);

3. air temperature at station level rising above 8^0C, i.e., an equal probability of snow or rain at 800m (e.g., 15th - 17th); and

4. no precipitation at station level but snow in the mountains (e.g., 7th, 14th).

4.4.2 Analysis of results

The mean monthly values for maximum and minimum air temperatures, the amount of precipitation and the percentage falling as snow are listed in Appendix 3, and the annual values were listed in Table 4.4. Over the 4538 days, 73.3% of all precipitation fell as snow. Table 4.6 compares the results obtained for the study area with data for Ben Nevis (Thom, 1974) and New Zealand (Prowse, 1981). The percentages for Ben Nevis

Table 4.6: Percentage of precipitation falling as snow.

Month	Cairngorms	Ben Nevis	New Zealand
DECEMBER	72.9%	44.0%	67.0% (June)
JANUARY	84.9%	53.0%	84.0% (July)
FEBRUARY	83.1%	53.0%	97.0% (August)
MARCH	70.4%	51.0%	58.0% (September)
APRIL	43.6%	49.0%	52.0% (October)
Altitude	800m	800m	1500m

during December to March are much lower than those inferred for the study area (probably owing to the more oceanic climate in the Western Highlands), but the values for April are higher. This difference could be due to the temperature lapse rate being higher in April (Barry, 1981) than that used in this study. The results are similar to those for the Southern Alps of New Zealand, the main difference being the high value for August in New Zealand.

Winters with low values included 1956/7 (42.9%), 1963/4 (50.6%), and 1970/1 (57.5%), and those with high values included 1961/2 (90.9%), 1968/9 (91.7%), 1969/70 (87.5%) and 1981/2 (91.8%). The results correlate well with known snowy or wet winters, particularly 1954/5, 1956/7, 1963/4, 1969/70, 1970/1 and 1973/4 (Green, 1973; Watson, 1976; Hudson, 1977; Jackson, 1977). A danger in comparing these results with the literature, however, is that most researchers have been concerned only with snowfall at low altitudes.

At this stage in the analysis (Figure 4.2), the wind speed and direction and the amount and type of precipitation are known for each of the 4538 days being studied. Snowdrift can now be calculated using this data.

4.5 SNOWDRIFT

4.5.1 Measurement of snowdrift

In the Scottish Highlands, snowfall is nearly always accompanied by wind, so it is deposited on lee slopes where it collects to considerable depths. This component of the supply of snow can be called "snowdrift" (Ward, 1981). Snowdrift is a product of the amount of precipitation falling as snow and the wind speed. The amount of snowdrift increases as the amount of precipitation and the wind speed increases. The value of snowdrift to be used to measure the natural potential of sites is the percentage of the total amount of snowdrift that would be deposited at a site on the basis of wind direction and the orientation of the site (see Figure 3.10). Snowdrift occurs on days when precipitation falls as snow and must exceed 1.0mm at station level.

The amount of snowdrift can be calculated from a simple equation (Ward, 1981; p.208):

$$D = Q \times T$$

where D is snowdrift, Q the amount of precipitation falling as snow (water equivalent)and T the rate of transport(the wind speed). The aim is to measure relative snowdrift rather than absolute snowdrift, which is the actual amount of snow deposited at a site.

To allow for the errors associated with both the amount of precipitation and the wind speed (see sections 4.2, 4.3 and 4.4) and to simplify the calculation of snowdrift, the daily values for Q and T are classed as shown in Table 4.7.

Table 4.7: Classes of wind speed and precipitation for use in the calculation of snowdrift.

Precipitation (mm) (Q)	Class	Wind speed (m/s) (T)
1.0 - 4.9	1	0.0 - 4.4
5.0 - 9.9	2	4.5 - 8.9
10.0 - 14.9	3	9.0 - 13.4
....	.	....
....	.	....
45.0 - 49.9	10	40.5 - 44.9

These classes assume that the relative importance of Q or T, on the drifting of snow, increases in a linear fashion, i.e., that 44.0m/s (10) is twice as important as 22.0m/s (5) in the drifting of snow. Although Föhn (1980) suggested that the influence of T on the rate of drifting is exponential, the lack of data on actual rates of drifting prevents the development of a more accurate model. The classes, therefore, will tend to underestimate snowdrift at higher wind speeds.

To illustrate the calculation of snowdrift a worked example is provided in Table 4.8. The summed values for the five days are 74 (WSW), 16 (WNW) and 12 (NNW). A site leeward to NNW winds would have a snowdrift value of 11.8%, while one leeward to WSW and WNW winds would have a value of 88.2%. If the directions for

Table 4.8: Worked example of the calculation of snowdrift.

	Precipitation (mm)	Wind speed (m/s)	Total	Wind
Day 1	12.5 (3)	8.0 (2)	6	WNW
Day 2	21.0 (5)	18.5 (5)	25	WSW
Day 3	6.0 (2)	21.5 (5)	10	WNW
Day 4	32.5 (7)	27.2 (7)	49	WSW
Day 5	16.2 (4)	11.0 (3)	12	NNW

which a site is leeward are determined, therefore, the individual site value for snowdrift can be calculated (see Figure 3.10). Appendix 4 gives details of the type of winter weather (rain, general thaw, snowdrift, wind-drift) on each day, and the class values of Q and T and those snowdrift on the appropriate days. Table 4.9 lists the distribution of snowdrift between the 8 wind directions for each winter. Appendix 5 contains data on the directions for which each of the 54 sites is leeward and the respective values of snowdrift for each of the last 30 winters.

4.5.2 Analysis of results

Over the 30 winters, some 33.0% of total snowdrift came from the SW, 28.0% from the SE, 23.8% from the NW and 14.9% from the NE (Table 4.9). There have been ten winters when more than 50% has come from the two eastern quadrants. Winters with a large proportion of snowdrift coming from the NE and SE include 1959/60 (66.4%), 1971/2 (76.7%) and 1979/80 (75.3%). It is often assumed that snow comes from a dominant wind direction. Slesser (1970), for example, commented that most snow in Scotland is associated with northerly winds, but the results in this study suggest that only 38.7% comes from the NE and NW. Manley (1969) noted that "..snow from a south-westerly airflow does not occur today,

Table 4.9: Directional source of snowdrift 1954/5 to 1983/4.

	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW
1954/5	8.1	10.9	3.8	4.7	12.6	5.2	19.0	35.8
1955/6	1.7	4.7	14.4	18.1	5.3	24.7	21.9	9.2
1956/7	2.2	3.0	25.0	22.0	13.8	20.3	9.9	3.9
1957/8	5.2	13.5	18.1	8.3	4.1	16.1	26.7	8.0
1958/9	1.2	6.6	11.2	12.0	10.0	27.8	15.4	15.8
1959/60	7.6	11.2	13.0	34.6	3.8	8.7	13.7	7.4
1960/1	2.1	0.0	11.9	31.7	9.9	28.0	8.6	7.8
1961/2	7.7	7.3	0.4	15.4	18.4	13.4	25.5	11.9
1962/3	4.7	31.7	20.3	1.3	10.0	15.3	6.3	10.3
1963/4	3.9	13.1	10.5	33.3	9.2	14.4	9.2	6.5
1964/5	5.2	5.5	4.2	5.2	9.1	33.9	23.5	13.4
1965/6	4.1	7.3	28.2	6.5	7.3	15.1	21.6	9.8
1966/7	1.6	1.2	2.6	24.3	5.8	36.1	15.3	13.1
1967/8	7.5	10.5	1.5	3.4	6.7	32.2	12.0	26.2
1968/9	5.2	16.6	22.9	10.6	3.6	19.5	8.6	13.0
1969/70	12.6	0.0	12.3	22.0	6.9	11.9	15.3	19.0
1970/1	5.4	30.7	10.8	7.8	15.7	16.3	6.6	6.6
1971/2	4.0	6.9	8.3	57.5	13.3	7.7	1.1	1.7
1972/3	1.9	0.0	4.7	19.0	14.3	40.2	10.3	9.7
1973/4	2.7	11.0	4.3	25.2	39.7	12.2	4.1	0.8
1974/5	5.8	4.6	2.0	7.5	23.9	16.1	25.9	14.1
1975/6	2.7	0.0	13.5	13.5	15.0	25.8	19.6	10.0
1976/7	7.5	17.9	10.3	18.8	19.1	4.4	17.6	4.4
1977/8	16.4	19.6	10.8	13.5	11.1	12.9	6.7	9.1
1978/9	1.7	13.6	26.4	10.4	20.8	14.9	2.6	9.5
1979/80	1.8	21.5	29.0	23.0	7.5	12.5	3.6	1.2
1980/1	1.5	9.4	8.6	6.4	5.3	31.6	14.3	22.9
1981/2	1.5	16.0	5.5	12.3	21.2	39.6	2.8	1.1
1982/3	7.7	2.6	0.4	9.5	20.4	33.3	13.5	12.7
1983/4	0.9	8.9	26.6	22.1	6.2	19.8	11.0	4.5
MEAN	4.7	10.2	11.6	16.4	12.1	20.9	13.1	10.7
S.D.	3.5	8.2	8.3	11.9	7.5	10.3	7.3	7.5

except in the occasional polar-air low.." (p.428), but this is surely not true, for 33.1% of total snowdrift comes from the SW (this is probably because Manley was concerned with snowfalls at low altitudes). Baker and Gordon (1980) assumed that winds from the south-east bring little snow. This is obviously wrong because 27.9% of snowdrift comes from the SE. Ward (1981), who measured snowdrift for the winters of 1977/8 to 1979/80, noted that

[illegible] storms are particularly scarce". Although true for

"...northwest storms are particularly scarce". Although true for his period of study it is false when viewed in the context of the last 30 winters. Some 18.2% of all storms (see later) come from the NW, and some 24.1% of all snowdrift comes from the NW, compared to only 9.1% for the period studied by Ward. The need to base work on longer-term data is evident.

Five-year moving averages of the directional source of snowdrift have been plotted and are shown in Appendix 5. Even with a five-year average, the data show remarkable variability. The clearest trend is the steady decline in snowdrift from the WNW. Snowdrift from the ENE has shown an overall, but erratic, increase. Snowdrift from the SSE, SSW and WSW show several peaks, most notably from the SSW during the early 1970s. This variability has four implications for the measurement of natural potential for downhill skiing.

1.Predction of future patterns of snowdrift is not possible, owing to the scale of the variability.

2. All sites should receive considerable snowdrift whatever their aspect.

3.Regularity in the distribution of snowcover on leeward and windward slopes may not be evident over a whole season.

4. The measurement of the depth of snow or the extent of snowcover, and its use in regression analyses, will have reduced significance because the pattern and depth of snowcover are likely to change after each snowfall (see Chapter 7).

Table 4.10 shows the temporal distribution of snowdrift during each winter. Most snowdrift comes in January (30.5%),

Table 4.10: Temporal distribution of snowdrift 1954/5 to 1983/4 (Figures are in percentages).

	December	January	February	March	April
1954/5	29.1	15.2	39.3	16.4	0.0
1955/6	41.4	31.1	16.1	7.5	3.9
1956/7	34.5	25.4	31.0	3.9	5.2
1957/8	25.4	22.8	21.8	20.7	9.3
1958/9	48.6	39.8	1.9	2.3	7.3
1959/60	44.8	32.1	18.6	4.6	0.0
1960/1	23.9	48.1	18.5	6.2	3.3
1961/2	16.0	41.3	20.4	15.4	6.9
1962/3	41.3	23.3	18.0	7.7	9.7
1963/4	22.9	6.5	18.3	47.7	4.6
1964/5	27.4	33.9	16.3	12.1	10.4
1965/6	35.1	9.0	17.6	27.8	10.6
1966/7	29.1	14.5	25.9	20.5	9.6
1967/8	16.9	24.3	21.7	21.7	15.4
1968/9	19.7	35.1	21.0	10.1	14.1
1969/70	13.6	17.0	27.9	24.2	17.3
1970/1	31.3	31.3	11.4	19.3	6.7
1971/2	11.3	44.5	22.4	20.7	1.1
1972/3	35.8	20.9	19.9	5.0	18.4
1973/4	25.8	51.0	9.7	13.6	0.0
1974/5	22.8	39.2	9.2	10.4	18.4
1975/6	0.0	52.3	13.5	26.9	7.3
1976/7	18.2	26.6	22.3	18.8	14.1
1977/8	11.7	46.5	13.2	18.7	9.9
1978/9	20.9	15.2	7.2	44.1	12.6
1979/80	39.1	34.6	6.0	20.3	0.0
1980/1	30.1	36.8	14.7	17.7	7.5
1981/2	14.4	23.9	20.4	38.5	2.8
1982/3	28.3	34.3	18.8	12.9	5.7
1983/4	15.1	40.1	19.0	23.0	2.8
MEAN	25.8	30.5	18.1	18.0	7.8
S.D.	11.1	12.1	7.4	11.0	5.5

followed by December (25.8%), February (18.1%), March (18.0%) and April (7.9%). The standard deviations listed at the foot of Table 4.10 indicate the variability between winters. The percent of total snowdrift coming in December, for example, has ranged from 0.0% in 1975/6 to 48.6% in 1958/9. This variability, both temporal and directional, means that no two seasons are alike, a finding that has implications for the measurement of natural potential. The variability in the amount of snowdrift and the relatively low percentage of precipitation falling as snow (72.9%) in December, means that snowcover over Christmas and the New Year (the busiest period for the ski areas) is less reliable than that for the months of January and February.

The annual totals for snowdrift are listed along with relevant meteorological parameters in Table 4.4. The 30-winter mean for the amount of snowdrift is 355, with a standard deviation of 110. The lowest value was 153 in 1963/4 (the winter during which the development at Mar Lodge failed) and the highest was 643 in 1983/4. Winters with high values include 1954/5, 1961/2, 1966/7, 1973/4, 1978/9, 1982/3 and 1983/4, and those with low values include 1956/7, 1960/1, 1963/4, 1970/1 and 1975/6. These results correlate well with known "good" and "bad" winters (Green, 1968; Manley, 1971; Watson, 1975).

If a storm is defined as a day with a value of snowdrift of more than 15 (a compromise between there being too many and too few storms to be of use; all storms are marked as "!" in Appendix 4), further analysis of the pattern of snowdrift is possible. These storms accounted for 29.5% of total snowdrift over the 30 winters, yet occurred on only 143 days (3.15% of the total of 4538 days). The proportion of snowdrift accounted for by these storms is expected to be a minimum figure for the following reasons:

1. no increase in the amount of precipitation with altitude was applied to the low level data;

2. the mean windspeeds are likely to be underestimated because

gradient winds are likely to be important during storms owing to cyclonic airflow (see section 4.3.2);

3. the gustiness of winds during storms has not been included; and

4. the calculation of snowdrift involved the use of classes of wind speed that were linear: the influence of wind speed on drifting is exponential (see section 3.3.3).

Of these storms, 11.2% came from the NE, 36.4% from the SE, 34.3% from the SW and 18.2% from the NW. Figure 4.7 shows the distribution of storms by wind direction and speed. There is a tendency towards a bimodal distribution for wind direction, with SSE and WSW being the two modes. Storms from the SSW are relatively infrequent. The mean wind speed of these 143 storms is 24.1m/s compared with a mean of 14.6m/s for all days (see section 4.3.2). 45.5% of the storms had a mean wind speed of more than 25m/s. The maximum speed was 40.5m/s on the 16.2.62 (although surface wind speeds may be considerably higher than this for reasons listed earlier). The largest value of snowdrift for a single storm is 49 recorded on 7.12.78, 28.1.78 and 24.3.84, and 48 on 17.2.55, 15.1.62 and 11.1.74. The combined storms of 10/11/12.1.74 and 28/29.1.78 had values of snowdrift of 102 and 84 respectively. The latter storm had a mean wind speed of 29.0m/s and precipitation of 56.4mm (water equivalent) at station level.

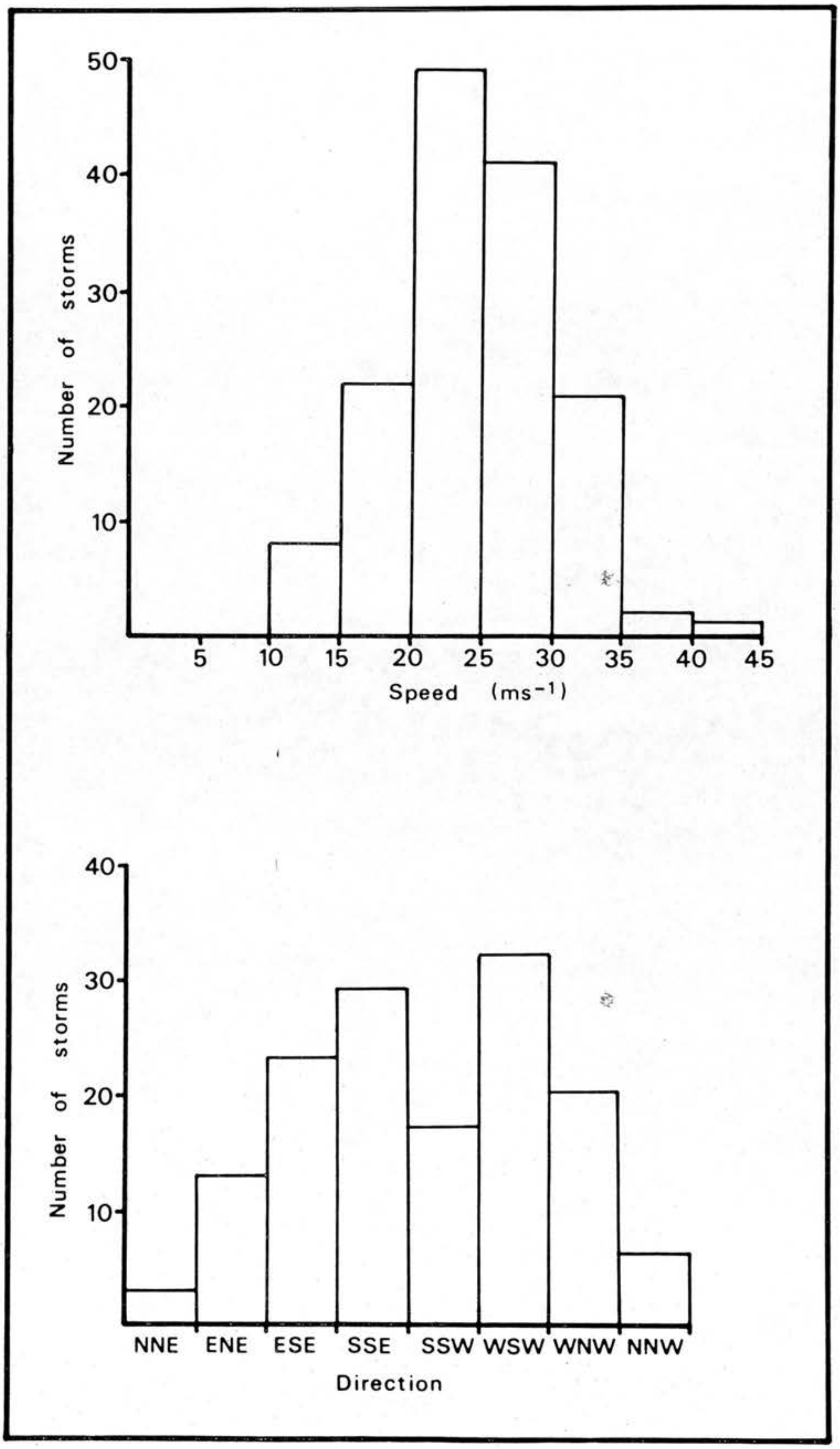


Figure 4.7: Frequency distribution of storms by wind speed and direction.

A synoptic classification of these storms can be partly achieved by using the daily register of weather patterns compiled by Lamb (1972), which covers 69 of the storms. Figure 4.8 shows the number of storms for each pattern. Storms are clearly associated with cyclonic or westerly airflow, so the gradient wind force would need to be measured if further analysis of these storms was undertaken. There are two anomalous storms, both

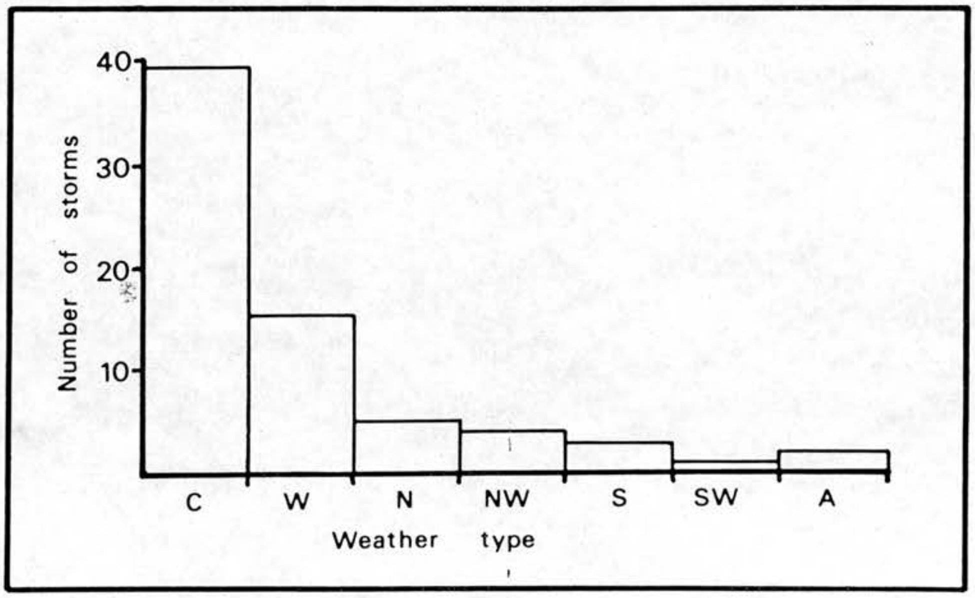


Figure 4.8: Synoptic classification of storms, according to Lamb (1972).

associated with anticyclonic airflow (28.2.55 and 21.1.61). This situation is feasible provided the anticyclone is situated to the west or east of the country or in an early or late stage of development (see Figure 1, p.24 in Lamb, 1972).

The influence of these few storms on the pattern and depth of snowcover should be considerable, with large amounts of snow being deposited on leeward slopes. Knowledge of these storms is very limited and most research into the drifting of snow is valid only for wind speeds of up to 20m/s (e.g., Martinelli, 1965; Dyunin et al., 1977; Dyunin and Kotlyakov, 1980; Fohn, 1980).

There is evidence of severe "snow shadows" across the study area. For example, the storm of 10/11/12.1.74 produced precipitation of 89.7mm at Braemar but only 47.1mm at Lagganlia. The storm on 19.1.60 gave 50.8mm at Braemar and only 12.7mm at Glenmore Lodge, while that on 17.2.55 gave 14.5mm at Braemar and 62.8mm at Glenmore Lodge. The existence of snow shadows implies that snowdrift may be over or under predicted for certain sites depending upon the path of the storm across the study area. The implications of this for regression analysis are discussed in greater detail in Chapters 7.

4.6 WIND-DRIFT

4.6.1 Measurement of wind-drift

Wind-drift is the amount of previously deposited snow which is transported and redeposited by the wind. Wind-drift is assumed to occur on a particular day when:

1. that day is within two days of a day with snowdrift;
2. temperatures have not risen above 0^0C between the last day with snowdrift and the day in question; and
3. the wind speed is more than 10m/s.

Wind-drift may also occur on any day when there was precipitation of less than 1.0mm (in the form of snow) and windspeeds of more than 15m/s, not meeting the requirements listed above.

These requirements are needed to meet the conditions for the drifting of deposited snow. Kobayashi (1965) and Takeuchi (1980) have measured the threshold wind speed for crystals of snow to be uplifted and held in suspension as between 6 and 8 m/s, depending upon the roughness of the surface of the snow. As the density of snow in the Scottish Highlands tends to be high (Langmuir, 1971; Ward, 1981), a threshold speed of at least 10m/s would be required, although no data are available on actual speeds. As strong winds create wind slab (Seligman, 1936), wind-drift was assumed to occur only on two consecutive days between days on which there was snowdrift.

Ward provided few data or results to support his conclusion that the relative impact of wind-drift is small in terms of the total supply of snow. Ward (pers. comm.) has suggested that sublimation of crystals of snow due to the relatively warm air temperatures and high humidity experienced in the Scottish Highlands will limit the distance they can be transported. Tabler and Schmidt (1972) calculated that crystals of snow may travel between 460 and 900m, depending upon the size of the crystals, before completely melting. Temperature, relative humidity and wind speeds, however, were all lower in the area where Tabler and Schmidt worked (SE Wyoming, altitude 2500m), than in the study area. The occurrence of high wind speeds and the low humidity experienced on some cold, precipitation-free winter days (Green, 1967), however, may encourage considerable amounts of wind-drift.

Owing to the absence of data on the redistribution of snow by the wind, and under what conditions, it is difficult to verify these assumptions. During fieldwork, observations were made of the weather, the condition of the snow and wind speeds. These notes, together with comments from the observers at Kingussie and

Drumochter, provide d the only opportunity to verify the assumptions. Days on which wind-drift was assumed to occur (see Appendix 4) and was observed were 10.4.83, 11.4.83, 4.1.84, 5.1.84, 19.1.84, 20.3.84, 21.3.84, 22.3.84 and 16.4.84. On the 16.4.84, for example, wind-drift of snow deposited overnight was occurring above 750m in westerly winds of 20m/s. The most severe wind-drift observed was that between 20th and 22nd of March at Cairn Gorm. Surface wind speeds at 600m were gusting to 25m/s.

Although outwith the period of study, the best example of wind-drift observed was that between the 18 and 20.3.85 in the Cairngorms. Snow had fallen on the 16.3.85 and was followed on the 18th and 19th by sunny weather with a very cold, SE wind of 20m/s, gusting to 25m/s on ridges. The amount of drift was immense, and partly obscured Cairn Gorm and Cairn Lochan. Snow was being lifted from the surface to several hundreds of feet in the air. By the afternoon of the 19th, wind slab had begun to form. The surface of the snow was quite hard on the 20th, but becoming softer with fresh snow.

The aim, as with the measurement of snowdrift, is to create a relative figure of wind-drift for each site. The basis for measurement is the capacity of wind to transport crystals of snow once they have been lifted from the surface of the snow. Most measurements of "wind-drift" have occurred in Antarctica where conditions are conducive to transport owing to the flat terrain, dry snow, low air temperatures and low relative humidity. Measurements have been reviewed by Mellor (1963), Radok (1977) and Takeuchi (1980). All theories of drifting have a logarithmic form and all agree that the rate of transport increases exponentially with wind speed. Use of any theory should produce similar results, therefore, on the relative amount of wind-drift. The most applicable equation, in terms of ease of calculation, is that developed by Budd et al. (1966) and used by Ward (1981).

The equation for the measurement of transport (Budd et al. 1966) is:

$$\text{Log } Q = 1.1812 + 0.0887\ V$$

where Q is the observed transport (grammes per metre per second) and V the wind speed (m/s). The influence of wind speed on Q has been plotted in Figure 4.9, and shows an exponential increase (note the similarity with Figure 3.3). As an example of its

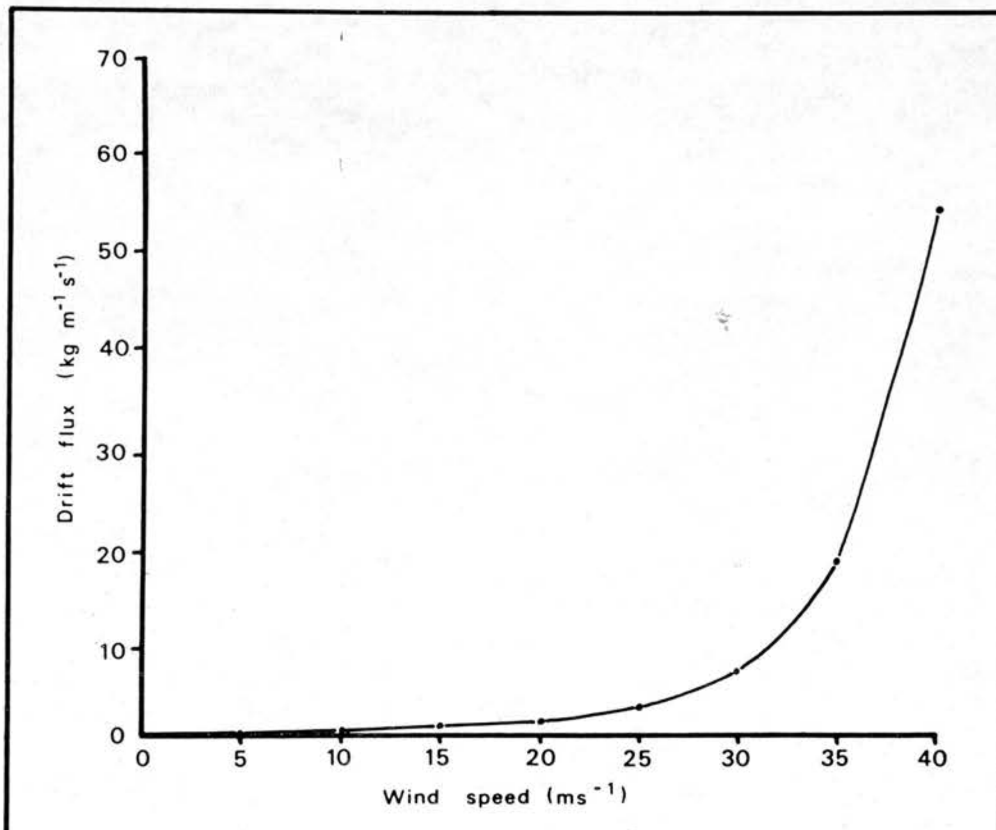


Figure 4.9: Drift flux and wind speed, based on data collected in Antarctica by Budd et al. (1965).

measurement, wind-drift was assumed to have occurred on 13.12.54 (all such days are noted in Appendix 4 with the symbol "--*--") with a geostrophic wind speed of 20.0m/s (Appendix 2), so the total transport would be 902.0 gm/m/s. The wind-drift for each day can be calculated by finding the appropriate wind speed in Appendix 2 and using the equation. If the total wind-drift for a winter is calculated, the proportion for each wind direction can be derived. One source of error in the calculation of wind-drift is the effect of strong gusts of wind. A day with a mean Vg speed of 20 m/s, for example, will have moderate wind-drift only (Figure 4.9). During the day, however, there may be strong gusts of wind (e.g., 30m/s) which would cause a greater redistribution of snow than a far longer period of lighter winds. This cannot be measured during this study owing to the absence of data.

4.6.2 Analysis of results

Table 4.11 shows the directional distribution of wind-drift for the 30 winters. Appendix 6 lists the total percentage wind-drift for each site (see section 5.2.11).

Conditions suitable for wind-drift existed on 12.3% of all days in winter. On many of these days the amount of wind-drift was small. As can be seen from Figure 4.9, the capacity of wind speeds below 20 m/s to transport snow is small. It is possible, therefore, for two or three days to account for most of the total wind-drift in any season, owing to the occurrence of very strong winds. In 1955/6, for example, some 67.1% of total wind-drift occurred on the 29 January with a mean wind speed of 35m/s. This phenomenon accounts for the dominance of one or two wind

Table 4.11: Directional source of wind-drift 1954/5 to 1983/4.

	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW
1954/5	0.0	1.9	1.6	32.2	12.8	42.7	5.5	3.2
1955/6	0.0	2.7	7.6	68.2	0.0	9.4	6.9	5.1
1956/7	0.0	0.0	4.6	0.0	52.2	36.2	5.0	2.2
1957/8	0.0	3.4	7.2	0.0	37.2	4.2	2.2	45.7
1958/9	0.0	0.0	15.0	31.8	10.4	17.6	5.6	19.6
1959/60	0.0	1.2	31.6	27.3	1.0	23.6	3.5	11.8
1960/1	0.0	0.0	4.9	22.8	3.2	6.3	54.9	7.6
1961/2	0.0	2.2	0.0	9.0	0.0	9.3	61.3	18.2
1962/3	0.0	20.0	17.1	0.0	42.0	8.2	7.4	5.5
1963/4	0.0	5.2	2.7	45.8	15.5	22.7	3.3	4.5
1964/5	33.7	7.8	6.6	3.4	1.2	23.3	23.7	0.0
1965/6	0.0	14.2	39.2	0.0	0.0	11.2	35.3	0.0
1966/7	0.0	4.8	3.2	3.7	10.8	20.7	55.6	1.1
1967/8	0.0	0.0	6.4	6.8	6.5	17.4	36.8	25.9
1968/9	0.7	2.5	6.3	23.1	0.6	23.9	18.6	24.2
1969/70	1.5	0.0	22.5	6.8	36.2	16.4	1.5	14.9
1970/1	8.3	2.7	0.0	47.8	4.1	32.2	4.8	0.0
1971/2	0.0	3.0	0.9	27.5	53.2	0.9	14.5	0.0
1972/3	0.0	3.3	0.0	39.5	34.8	11.1	10.2	1.2
1973/4	0.0	1.4	0.0	13.3	66.5	8.0	0.0	10.6
1974/5	0.0	0.7	0.0	0.9	39.0	10.1	42.5	6.6
1975/6	1.4	2.1	7.1	8.4	2.0	73.8	5.0	0.0
1976/7	6.9	4.3	1.0	25.0	32.8	3.6	8.8	17.9
1977/8	1.7	1.7	9.5	58.7	0.0	13.0	2.8	12.6
1978/9	2.7	18.2	28.4	10.1	25.1	2.0	5.4	7.9
1979/80	0.6	53.0	8.1	19.5	5.1	3.4	5.4	4.7
1980/1	5.3	5.0	45.4	5.8	6.9	4.7	24.7	2.0
1981/2	28.2	0.0	1.2	48.8	5.7	5.1	2.0	8.4
1982/3	7.1	0.0	0.0	0.8	8.4	13.4	33.9	36.4
1983/4	0.3	0.6	1.0	2.2	10.1	70.2	0.5	14.8
MEAN	3.3	5.4	9.3	19.6	17.4	18.2	16.2	10.4
S.D.	7.8	10.2	12.0	19.2	18.9	17.6	18.0	11.0

directions each season, as shown in Table 4.11. In 1975/6, for example, 73.8% of total wind-drift came from the WSW. It is possible therefore for some sites to have very high values and for others to have very small values.

The most notable feature of the directional distribution of wind-drift is the virtual absence of winds from the NE. Sites facing SW may receive little wind-drift, therefore, as they are likely to have a fetch to the NE. The standard deviations listed at the foot of Table 4.11 are very high (often higher than the mean) for most directions. This indicates the scale of variation between the winters and raises the possibility that wind-drift is spatially more variable than snowdrift. The influence of wind-drift, therefore, may be more easily detected than that for snowdrift in regression analyses (see Chapter 7).

4.7 DAYS WITH THAW CONDITIONS

4.7.1 Measurement

Days with maximum air temperatures above $+0^0$C are defined as days with thaw conditions. These days can be subdivided into:

A. days with rainfall of less than 1.0mm (marked as "*" in Appendix 4); and

B. days with rainfall of 1.0mm or more (marked as "RAIN" in Appendix 4).

Table 4.12 shows the number of days of each type for each of the 30 winters.

4.7.2 Analysis of results

The mean number of days with thaw conditions in a season is 55, ranging from 25 days in 1978/9 to 77 days in 1956/7. Each winter there is an average of 21 days with more than 1.0mm of rainfall, ranging from 9 days in 1981/2 to 36 days in 1979/80. Thaw days are most frequent in April when thaws can be prolonged. It was noted earlier (see section 4.4.2) that only 43.6% of all precipitation in April falls as snow.

The mean Vg speed for these days is 12.7m/s which is below

Table 4.12: Temporal distribution of days with thaw conditions.

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL		
	A	B	A	B	A	B	A	B	A	B	SUM
1954/5	4	9	3	3	0	0	0	2	21	8	50
1955/6	3	6	5	1	0	6	15	4	13	9	62
1956/7	9	8	2	6	0	4	16	10	15	7	77
1957/8	9	3	8	2	6	4	4	2	13	5	40
1958/9	0	0	1	0	13	5	16	8	15	11	68
1959/60	0	3	2	1	5	4	11	2	16	14	56
1960/1	3	5	0	1	10	5	19	6	14	9	72
1961/2	3	4	0	4	7	3	0	0	15	4	40
1962/3	5	3	0	0	0	0	9	14	14	8	53
1963/4	4	3	6	6	6	4	5	2	15	9	60
1964/5	0	6	2	1	3	5	6	5	13	10	51
1965/6	1	1	4	3	3	6	12	7	7	6	50
1966/7	0	4	5	6	7	6	3	11	17	5	64
1967/8	6	9	6	2	0	0	8	11	17	5	64
1968/9	4	1	7	3	1	0	6	2	15	6	45
1969/70	4	3	2	3	0	0	5	3	7	6	33
1970/1	5	4	2	5	6	1	9	6	18	5	61
1971/2	11	9	0	1	0	0	12	2	16	13	64
1972/3	7	1	2	4	7	2	18	4	9	6	60
1973/4	6	3	3	3	6	1	9	1	27	3	62
1974/5	6	11	3	8	9	0	3	3	9	10	62
1975/6	17	10	4	5	7	1	6	1	21	1	73
1976/7	0	0	1	1	0	0	6	10	6	14	38
1977/8	10	4	5	1	1	0	4	8	13	1	47
1978/9	1	3	0	0	0	0	0	2	13	6	25
1979/80	0	6	0	0	8	9	3	6	14	15	61
1980/1	6	5	7	4	4	3	6	9	24	1	69
1981/2	1	1	1	2	0	1	8	0	18	5	37
1982/3	5	1	2	9	0	0	7	7	7	6	44
1983/4	5	8	0	1	4	0	6	0	16	0	40
MEAN	5.0	4.7	2.8	3.1	3.8	2.4	7.8	5.1	13.8	7.5	56
S.D.	4.0	3.6	2.5	2.7	3.7	2.6	5.3	4.0	5.1	4.0	13.7

A: Days with high temperatures and rainfall of less than 1.0mm.
B: Days with high temperatures and rainfall of more than 1.0mm.

the mean wind speed of 14.6m/s for all 4538 days. The combination of warm temperatures and strong winds, particularly over massifs is often of greater importance in the melting of snow than global radiation (Obled and Harder, 1980; Morris, 1982; Prowse, 1981). This combination can lead to devastating thaws midway through a season, as in 1955/6, 1956/7, 1958/9, 1965/6, 1967/8, 1972/3 and 1980/1, which can remove most, if not all, of the snow.

4.8 CONCLUSIONS

1. The geostrophic wind speed was found to be quite strongly correlated with surface wind speeds recorded on the summit of Cairn Gorm.

2. The values of the geostrophic wind speed are likely to be consistent, but slight, overestimates owing to the use of a single value for the density of air.

3. The mean speed of the geostrophic wind over 30 winters was 14.6m/s.

4. The prediction of winter weather for altitudes of approximately 800m from low altitude data is possible and quite accurate.

5. Over the last 30 winters, 73.3% of all precipitation at 800m has fallen as snow.

6. In the study area, snowfall is not dominated by any particular wind direction, although 33% is associated with SW winds and 28% with SE winds.

7. Some 29.5% of total snowdrift occurred on only 143 days (3.15% of the total). The importance of these storms is likely to be

underestimated owing to the use of low altitude data on precipitation, the use of linear rather than exponential classes and the absence of the gradient wind force in the calculation of the geostrophic wind speed.

8. The amount of precipitation varies considerably across the study area (holding altitude constant).

9. Wind-drift is dominated by a few days in any one winter with very strong wind speeds and is spatially more variable, therefore, than snowdrift.

10. Over one-third of all days in winter have thaw conditions which can remove most of the snowcover at any time during the winter. The consistency of snowcover is of paramount importance, therefore, in the identification of sites for downhill skiing.

The next chapter examines the data, including that for snowdrift and wind-drift, prior to the multivariate analysis of the data in Chapter 6.

CHAPTER 5: THE MORPHOLOGY OF SITES: DESCRIPTION AND ANALYSIS OF DATA.

5.1 INTRODUCTION

Eleven variables were identified in Chapter 3 to represent the five processes that control the consistency of snowcover. These variables were measured for 54 sites chosen at random from the total population of 180 sites within the study area. This chapter has three aims:

1. to describe the morphology of these 54 sites;
2. to examine differences between the morphology of sites in the Cairngorm Mountains and that of sites in the SE Grampian Highlands, and
3. to examine the relationships between the variables and to raise some implications these have for the consistency of snowcover at the sites.

5.2 DECSRIPTION OF THE DATA

5.2.1 Introduction

This section critically examines the measurement of each variable, provides descriptive statistics for each and examines extreme values within the data. It will also provide a context within which the results examined in Chapters 6 and 7 can be placed. Descriptive statistics for each variable were computed using the SPSS "CONDESCRIPTIVE" subprogram (Nie et al., 1975). The matrix of 54 sites by 11 variables is listed in Appendix 7.

The significance of skewness or kurtosis at the $p = 0.05$ level is tested using the equations:

$$\text{skewness} = \sqrt{\frac{6}{n}} \times 1.96 \qquad \text{kurtosis} = \sqrt{\frac{24}{n}} \times 1.96$$

where n is the number of sites. For 54 sites, values of 0.653 and 1.307 are significantly different from zero at the $p = 0.05$ level for skewness and kurtosis respectively.

Table 5.1 shows descriptive statistics for all eleven variables. A detailed analysis of the results is given for each variable below.

Table 5.1: Descriptive statistics for the 54 site matrix.
CV = Coefficient of variation.

	Mean	Stand. Dev.	CV	Min. value	Max. value	Skew-ness	Kurt-osis
1	387.44	51.02	13.2	293.14	515.24	0.392	-0.333
2	0.114	0.02	45.6	0.016	0.300	0.965	2.151
3	14.8	5.1	34.5	5.9	27.2	0.496	-0.419
4	0.334	0.143	42.8	0.09	0.61	0.236	-1.105
5	1946	1241	63.8	0	5850	0.544	0.531
6	966	106	11.0	801	1268	0.741	0.661
7	967	125	12.9	599	1315	-0.336	1.364
8	2721	522	19.2	1369	3737	-0.190	0.026
9	51.8	11.6	22.4	26.1	75.2	0.055	-0.219
10	44.8	20.5	45.8	5.4	85.2	0.110	-0.736
11	107	43.2	40.4	30	180	0.132	-1.099

1 Global radiation (langleys)
2 Basin ratio (ratio)
3 Gully side slope (degrees)
4 Form ratio (ratio)
5 Fetch (metres)
6 Top altitude (metres)
7 Topographic rise (metres)
8 Leeward slope (metres)
9 Snowdrift (percent)
10 Wind-drift (percent)
11 Topographic rise (degrees)

5.2.2 Global radiation

Global radiation is the maximum possible incidence of radiation on a surface on any day of the year (full definitions of each variable were given in Chapter 3). The 2nd of April was the date used in this study. Measurement of global radiation requires data on the mean slope of the gully and its bearing, the latitude of the site (taken to be 57^0N for all sites) and the day of the year. A computer program compiled by Williams et al. (1972) was modified (by Dr. D.J. Sutherland) to calculate global radiation at single points. The original program calculated the angle and bearing of a slope from the altitude of each intersection on a fine grid and used the data to produce maps of global radiation. The modifications involved the removal of the requirement to have a grid, which was replaced with point data on the angles and bearings of slopes. The use of a fine grid was precluded on grounds of time because of the size of the study area (40km by 40km).

The absence of a grid meant that the influence of shading could not be incorporated into the calculation of global radiation. Previous applications of computer programs have incorporated shading but over much smaller study areas than the present one (e.g., Williams et al., 1972; Dozier and Outcalt, 1979; Isard, 1983). Shading is possible from two sources:

1. surrounding mountains (sites facing into the Lairig Ghru, Lairig an Laoigh, Glen Avon and Glen Einich, for example, would be shaded by mountains on the opposite side of the valley); and
2. the basin surrounding the gully, which would be particularly important in deeply-incised basins, e.g., Allt a' Choire Ghuirm (32) or streams which were well below the highest altitude within the basin, e.g., Allt Coire an t-Sabhail (24).

The results make it possible, however, to differentiate between sites with different slopes and bearings, and offer relative data on theoretical amounts of global radiation, i.e., site A receives more global radiation than site B.

The mean value of global radiation on April 2, for the 54 sites, is 387.47 langleys with a standard deviation of 51.02 langleys, giving a coefficient of variation of 13.2%. Figure 5.1 shows the frequency distribution of the values. The data have a distribution which is approximately normal with a skewness of 0.392 and kurtosis of -0.333. The values range from 293.14 langleys at Allt Creag Dubh (site 19) to 515.24 langleys at Buidheannach Burn (site 51).

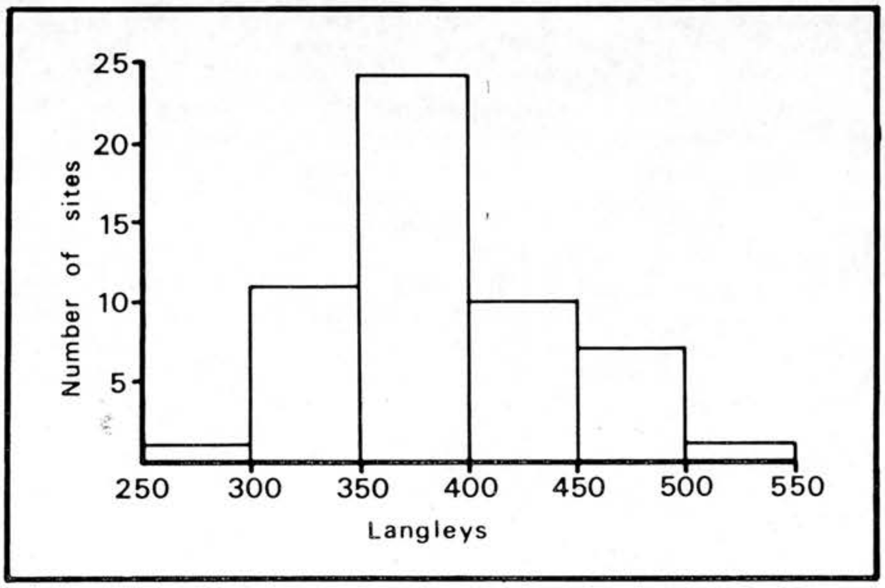


Figure 5.1: Frequency distribution of global radiation (54 sites)

Allt Creag Dubh (19) lies on the northern slopes of Beinn Mheadhoin. With steep slopes of 18^0 and a bearing of 349^0,this site receives little radiation until mid-March. Buidheannach Burn

(51) lies on the south-facing slopes of Cairn Toul to the west of the Devil's Point. With a bearing of 181^0 and a slope of20.5^0 this site receives intense radiation from mid-morning to mid-afternoon. For part of the winter, however, the site is partly shaded by Beinn Bhrotain (1157m), 2.5km to the south.

Other sites with high values all face SE or SW and include Allt Clach nan Taillear (22), Allt a' Choire Ghuirm (32), Allt an t-Sneachda (34), Alltan na Beinne (35), Allt Clais Bheag (45) and Allt Coire Lagain (48). Sites facing NE or NW have particularly low values and include Allt a' Choire Odhair (7), Allt Easan na Bruaich (10), Allt na Ciste (16), Allt Coire Buidhe (18), Allt a' Mhaim (26) and Allt Coire a' Chaisteil (46). A large number of sites lie within one standard deviation of the mean. These sites have moderate slope angles and face ENE, ESE, WSW or WNW.

5.2.3 Basin ratio

Basin ratio is the product of the depth of a basin divided by its width as measured at the mid-point of the gully. Although basin ratio was measured at the mid-point of each gully to allow comparisons between sites to be made, the basin may be more or less incised above or below this point. Although this feature is not incorporated into the definition, it may influence the entrapment and, hence, the consistency of snowcover at a site.

The mean basin ratio of the 54 sites is 0.114 with a standard deviation of 0.052, giving a coefficient of variation of 45.6%. A value of 0.114 is equivalent to a basin 1000m in width with a depth of 114m. Figure 5.2 shows that the frequency distribution is not normal. The distribution has a strong positive skew of 0.965 and a very high value for kurtosis of 2.151. Both values are significantly different from zero at the p = 0.05 level. The data was transformed for use in regression analyses, but not for use in principal components analysis (Chapter 6). After a square root transformation, skewness was 0.081 and kurtosis 0.762.

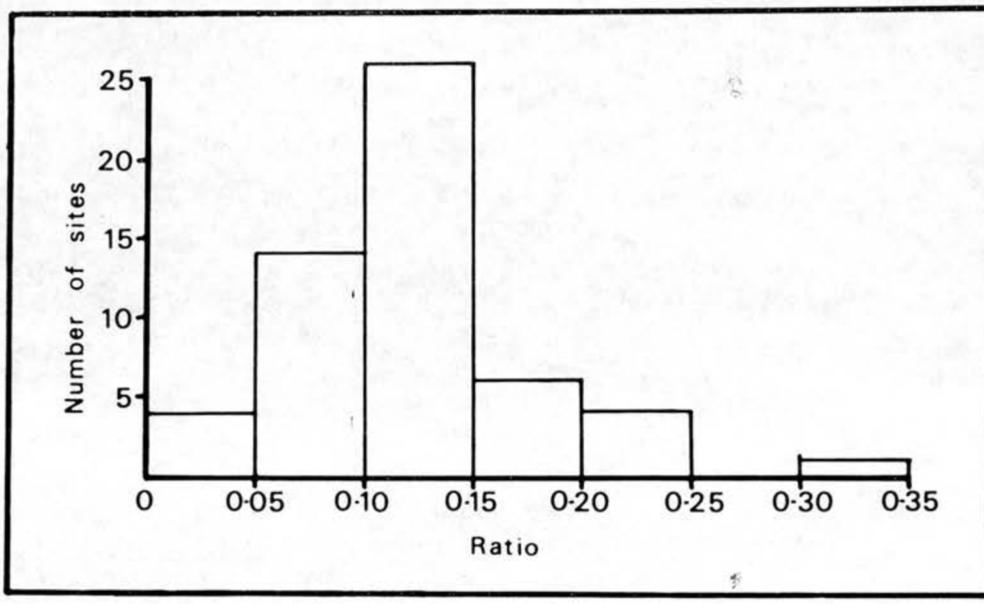


Figure 5.2: Frequency distribution of basin ratio (54 sites).

Allt a' Choire Ghuirm (32) has a ratio of 0.300. This site illustrates a limitation of the definition of basin ratio. Above the mid-point of the gully, the basin widens and becomes much more open, but below the mid-point it becomes narrow and deep relative to its upper reaches. Three other sites are deeply incised: Allt Fuaran Diotach (6) (0.218), Allt Coire a' Chaisteil (46) (0.213) and Beanaidh Bheag (11) (0.206). Allt Fuaran Diotach has a high value because the transect includes a very steep headwall rising 150m to the north of the gully. The steep and high NW spur of Braeriach forms the north and east boundary of the basin for Beanaidh Bheag and this is responsible for the high value.

Sites with low values of basin ratio are shallow, e.g., Allt Coire Lagain (48), Allt a' Choire Ghuirm (12), two sites on Derry Cairngorm (29, 30), Allt an Tuirc (49) and Allt a' Bhealaich Bhuidhe (50). The last two of these sites are good examples of very wide basins (approx. 1500m) which are, however, still deep (approx. 100m). Sites expected to have low values, e.g., Allt Creag Dubh (19), Allt Coire an t-Sabhail (24) and Buidheannach Burn (51) have average values because the basins are very narrow (a basin 10m deep and 100m wide has the same basin ratio as one 100m deep and 1000m wide).

5.2.4 Gully side slope

Gully side slope is the angle of the sides of a gully measured at transects across it at intervals of 100m along its length. The value used is the mean of all the transect values. Side slope was measured on OS maps at the scale of 1:10,000. Measurement of gully side slope requires that the lip or boundary of the gully be identified. Although, the boundaries of some gullies were easily identified because of the curvature of the contours, e.g., Allt Meall Dubhaig (4), Allt Coire an t-Sabhail (24), in most cases this was not possible. An arbitrary boundary at 20m on either side of the stream was required. Although a width of 40m may appear large, it was needed to allow sufficient relief to be visible on the maps to enable the angle of slope to be measured. It discriminates, therefore, against steep-sided, narrow gullies, although such gullies still have the highest values, e.g., Allt Meall Dubhaig (4) (24.7^0), Allt Coire an t-Sabhail (24) (22.4^0).

A further problem is that of variations in the angle of slope along the length of the gully. Most gullies, for example, have shallow slopes near the source of the stream, while transects further down the stream have slopes steeper than the mean value. Plate 2 shows the gully of Allt Creag an Leth-choin (13) near to its source where the side slopes are very shallow. Further down the gully the side slopes become steeper, as shown in Plate 3.

Plate 2: Gully side slopes near to the source of Allt Creag an Leth-choin (13).

Plate 3: Gully side slopes at the mid-point of Allt Creag an Leth-choin ('13).

Although both photographs were taken on the 15.6.85, Plate 3 shows remnants of winter snow, which suggests that the snow is more consistent where the gully side slopes are steep. The need to derive a mean value for each gully, however, meant that such variation had to be ignored although, as defined, the variable measures the relative differences between the sites accurately.

The mean value of gully side slope for the 54 sites is 14.8^0 with a standard deviation of 5.1^0, giving a coefficient of variation of 34.5%. Figure 5.3 shows that the data have a moderate, positive skew of 0.492 and negative kurtosis of -0.419.

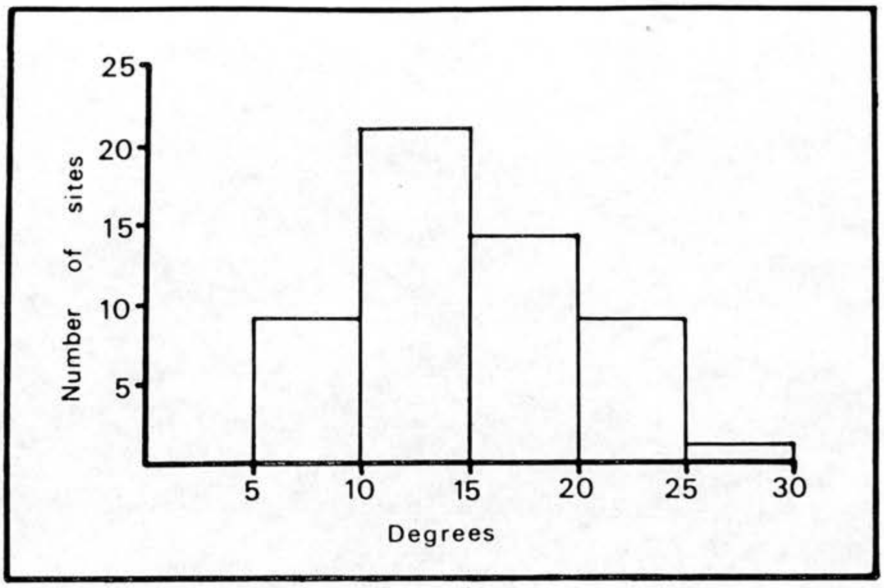


Figure 5.3: Frequency distribution of gully side slope (54 sites)

Allt Coire a' Chaisteil (46) (27.2^0), Allt Meall Dubhaig (4) (24.7^0), Allt Buidheannach (9) (24.3^0), Allt a' Choire Odhair (7) (23.5^0) and Allt a' Choire Bhuidhe Mhoir (47) (22.9^0) have the highest values. A limitation of gully side slope, as defined, is that some gullies do not have a boundary and are a continuation of the slopes of the basin. The gully of Allt Coire an Chaisteil (46), for example, lies in a deep basin (see section 5.2.3) and has no boundary on 1:10,000 maps. It is possible that such gullies will be less efficient in the entrapment of snow than others, such as Allt Meall Dubhaig (4) and Allt Buidheannach (9), where there is a sharp break in the angle between the gully and the basin. Allt Meall Dubhaig (4) should have deeper snowcover, therefore, than Allt Coire a' Chaisteil (46) even though the gully side slope is similar. Apex angles were not measured because the boundary of the gully had to be identified.

Sites with low values of gully side slope include Allt Creag Dubh (19) (5.9^0), Allt Coire an Lochain (14) (6.8^0), Derry Cairngorm(30) (6.9^0) and Buidheannach Burn (9) (8.7^0). As was shown earlier (see section 3.2.3), these gullies should entrap little snow as they do not present a steep enough obstacle to the flow of air.

5.2.5 Form ratio

Form ratio is the product of the area of a basin divided by the square of its maximum length. Sites with a high value of form ratio are essentially wide relative to their length and usually have a large surface area. This area may entrap large quantities of snow and "starve" the gully of snow. A low value of form ratio implies that the basin is narrow relative to its length, and that the area of the basin is small, so the gully tends to be the dominant feature of the basin.

The area of each basin was measured from OS maps at the scale of 1:25,000 using a planimeter and checked using a fine grid marked on a sheet of clear plastic. The only problem in the measurement of form ratio is that of defining the boundary of the basin. Some basins are quite easily defined, e.g., Allt a' Mharcaidh (1), Allt a' Choire Chais (15) and Allt Coire Fionn (38), but many present difficulties. Particularly difficult are those where the stream runs over an exposed slope, e.g., streams on Beinn Mheadhoin (19,20,21) and Derry Cairngorm (29,30).

The mean form ratio is 0.334 with a standard deviation of 0.143, giving a coefficient of variation of 42.8%. Figure 5.4 shows the frequency distribution of form ratios. The distribution has a slight positive skew (0.236) but a high value for kurtosis of -1.105.

Examples of sites with low values include Allt Buidheannach (9) (0.09), Allt Easan na Bruaich (10) (0.11), Allt a' Choire Chlachaich (42) (0.14) and Buidheannach Burn (51) (0.15). These sites are all narrow relative to their width. Sites with high

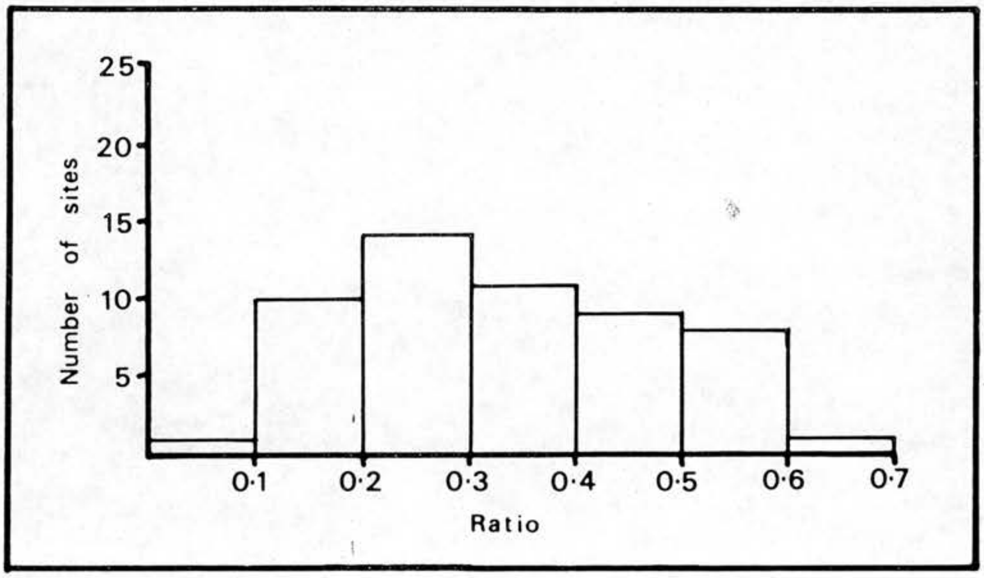


Figure 5.4: Frequency distribution of form ratio (54 sites).

values include Allt a' Gharbh-choire (39) (0.61), Allt Coolah (40) (0.59), Allt a' Chram-alltain (2) (0.56), Allt a' Choire Odhair (7) (0.54) and Allt Coire Dhondail (8) (0.53). These basins have large areas of slope which may entrap snow before it reaches the gully (see Plate 4 in Chapter 6). This is most clearly seen for the steep headwalls of the Gharbh-choire and Coire Dhondail.

5.2.6 Fetch

Fetch is the extent of relatively flat terrain upwind of the source of the stream from which snow may be blown onto the site. The value used in the analysis was the sum of the fetch measured for wind directions such as NNE, ENE, etc.. Changes of more than 10^0 in the angle of slopes, and major obstacles (e.g., cliff, lochan, stream) were used as the boundary of the extent of fetch. The measurement of fetch involves subjective decisions about the location of the boundary. Where the boundary of the fetch is difficult to identify, its limit is taken to be any angle of slope of more than 10^0 and not a change in the angle of the slope of 10^0.

The use of fetch as a measure of the supply of wind-drift to a site pays no attention to the nature of the land surface apart from major topographical features. Snow is more easily redistributed by the wind when the surface of the land measured as fetch is relatively smooth, e.g., the plateau between Braeriach and Einich Cairn, and less easily when the surface is rough, e.g., the plateau at the head of Glen Einich, and the Moine Bhealaidh. Rough surfaces have a large number of hollows which must be first filled by snow before maximum wind-drift can occur (Granberg, 1980). For this study, however, it is assumed that a site with long fetch (even if rough) will receive more snow by drifting than a site with shorter fetch.

The mean fetch is 1946m with a very high standard deviation of 1241m, giving a coefficient of variation of 63.8%. Figure 5.5 shows the frequency distribution of the data, which has moderately strong skewness (0.544) and moderate kurtosis (0.531).

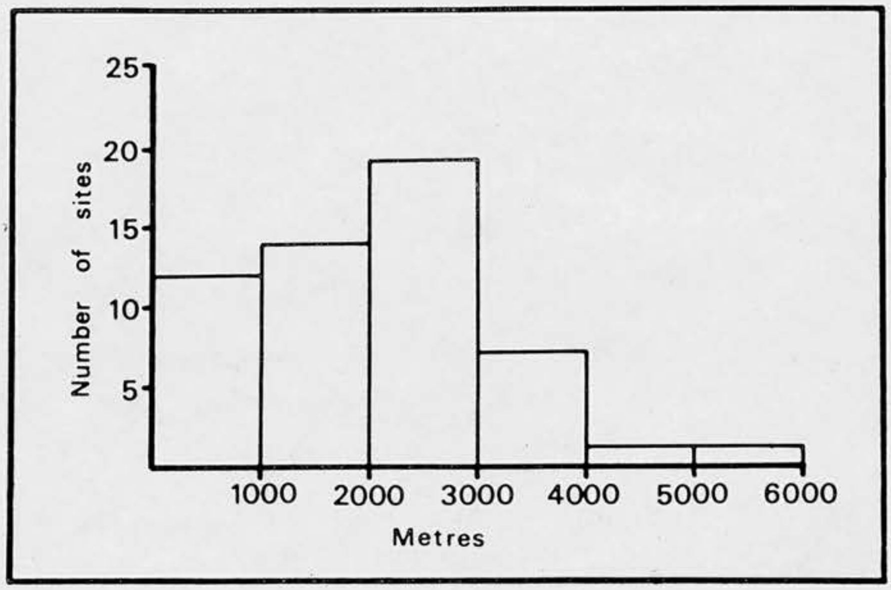


Figure 5.5: Frequency distribution of fetch (54 sites).

Allt Clais nam Balgair (31) has the longest fetch (5850m) which backs to the north, west and south on to the extensive Moine Bhealaidh. Allt Clach nan Taillear (22) (3975m) and Allt a' Choire Mhoir (23) (3625m) back onto the summit plateau of Ben Macdui. Sites in Glen Feshie (1 to 7) all have above average values of fetch. Some sites have no measurable fetch, e.g., Allt Buidheannach (9), Allt Easan na Bruaich (10) Allt Coire an t-Sabhail (24) and Allt Toul (25), or very little, e.g., Allt Iar-choire Sneachdach (33), Allt Clais Mhor (43), Buidheannach Burn (51) and Allt Creag Dubh (19). It may be noted that sites with little or no fetch are those with low values of basin ratio and form ratio. The sources of these streams tend to be located on exposed slopes, well below the summit of the mountain, which accounts for the virtual absence of fetch at these sites.

5.2.7 Top altitude

Top altitude, i.e., the altitude of the source of the stream, was measured from OS maps at the scale of 1:25,000. The minimum value possible was 800m; this being one of the requirements for the identification of sites (see Chapter 1).

The mean value of top altitude of the 54 sites was 966m with a standard deviation of 106m, giving a coefficient of variation of 11.0%. Figure 5.6 shows the frequency distribution which has a

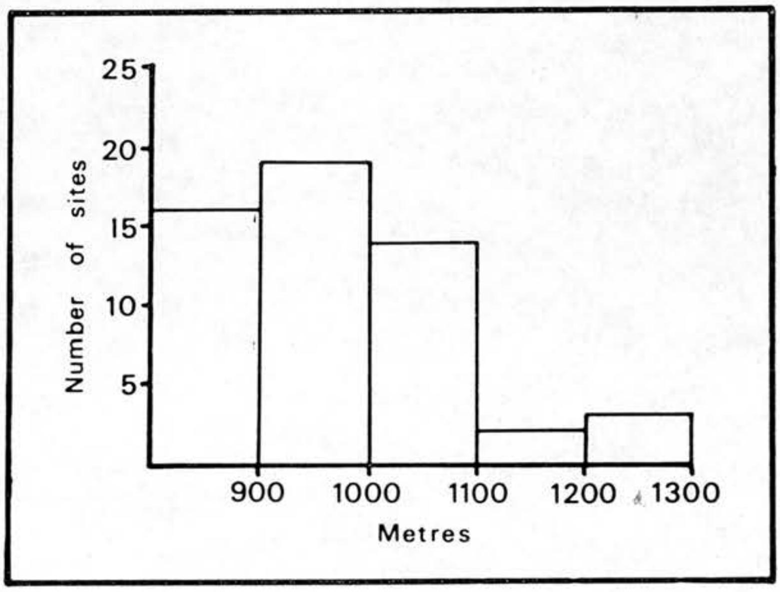


Figure 5.6: Frequency distribution of top altitude (54 sites).

high positive skew of 0.741. As this value is significantly different from zero at the $p = 0.05$ level, the data were transformed for use in the regression analyses (see section 7.1.2) and for use in the calculation of correlation coefficients (see section 5.3.1). A square root transformation was used. The value of kurtosis was 0.661.

Three sites have values more than two standard deviations above the mean: Allt a' Choire Mhoir (23) (1268m), Allt Clach nan Taillear (22) (1232m) and Allt Coire Dhondail (8) (1208m). The Feith Buidhe (17) (1145m) and Allt na Ciste (16) (1097m) also have high values of top altitude. The sources of these streams are all located on the summit plateaux of the Cairngorms.

There are nine sites with values of below 860m (more than one standard deviation below the mean) and include Allt Coolah (40) (801m), Allt Toul (26) (805m), Allt Coire Fhearneasg (54) (828m) and Allt a' Gheoidh (41) (838m). Perhaps most notable is that all but two of the nine sites below 860m are located in the SE Grampians (see section 5.3).

5.2.8 Topographic rise

Topographic rise is the total rise of the terrain (in metres) for 10km upwind of a site and measured for eight directions (NNE,ENE...). The values were summed and divided by the number of directions. Although time consuming, for all 54 sites it was equivalent to measuring the topographic rise along 4320km, topographic rise is relatively easy to measure.

The only limitation of this definition is that a mean value for each gully had to be used. For some sites, the topographic rise to the NNW may be far greater than that to the SSW, so winds from the NNW would be subject, therefore, to greater orographic rise and turbulence than winds from the SSW. The influence of topographic rise on the consistency of snowcover, therefore, may vary according to the wind direction. For the purpose of this study, however, a mean value had to be used.

The mean value of topographic rise is 967m with a standard deviation of 125m, giving a coefficient of variation of 12.9%. Figure 5.7 shows the frequency distribution which has slight negative skewness (-0.336), but a high value of kurtosis (1.136). Sites with values more than one standard deviation below the mean are all located along the northern edge of the Cairngorm Mountains with the exception of Allt Iar-choire Sneachdach (33). These sites face north and west over the wide valley of Strathspey. Allt Coire Dhondail (8), Allt Clach nan Taillear (22) and Allt a' Choire Mhoir (23) have very high values and also have high values of top altitude (see section 5.2.7).

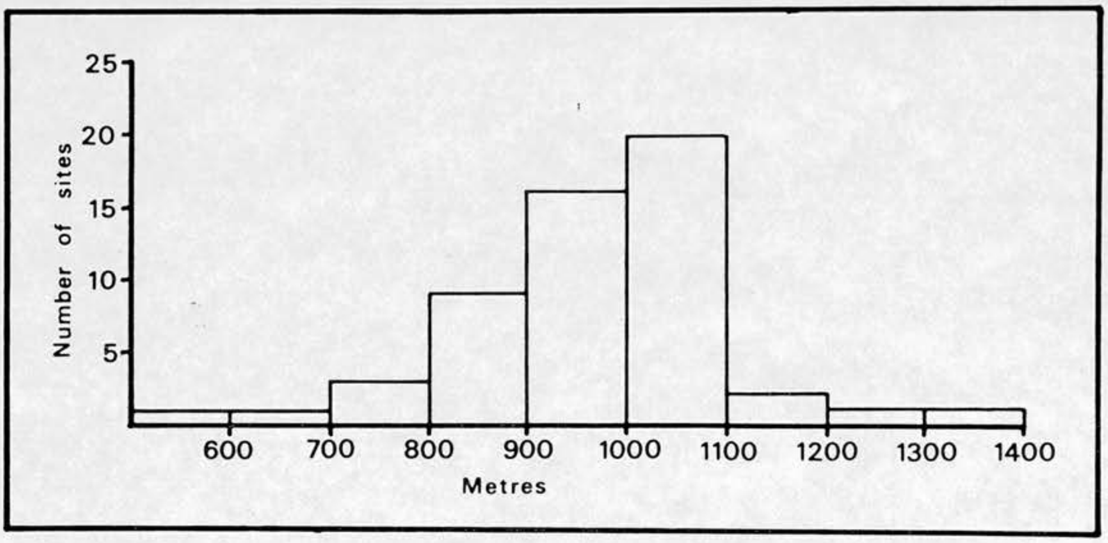


Figure 5.7: Frequency distribution of topographic rise (54 sites)

To some extent, these values can be explained by the measurement of topographic rise to the source of the gully and so may be biased to sites with high values of top altitude. The null hypothesis that topographic rise and top altitude are not related can be tested using Pearsons product moment correlation coefficient test. The correlation was 0.33 which is significant at the p = 0.01 level (see section 5.4). A correlation of 0.33 however, means that only 11% of the variation in topographic rise can be accounted for by variation in top altitude. Analysis of the data in Appendix 7 shows that many sites with low values of top altitude have high values of topographic rise and vice versa.

5.2.9 Leeward slope

The leeward slope of a site is the extent of leeward slope for 10km upwind of a site and measured for eight wind directions. The eight values were summed and divided by eight. Leeward slope was measured to the source of the stream, so that the gully itself was not measured as a leeward slope. Interpretation of the values must take into account the nature of the terrain. A low value, e.g., Allt Fuaran Diotach (6), Allt Coire Dhondail (8), may consist of very steep headwalls upwind of the site or just one short slope. Steep lee slopes would entrap more snow than less steep lee slopes. As with topographic rise, the definition of leeward slope is limited by the use of a single value for each site (see section 5.2.8).

The mean value of leeward slope is 2721m with a standard deviation of 522m, giving a coefficient of variation of 19.2%. Figure 5.8 shows the frequency distribution which is

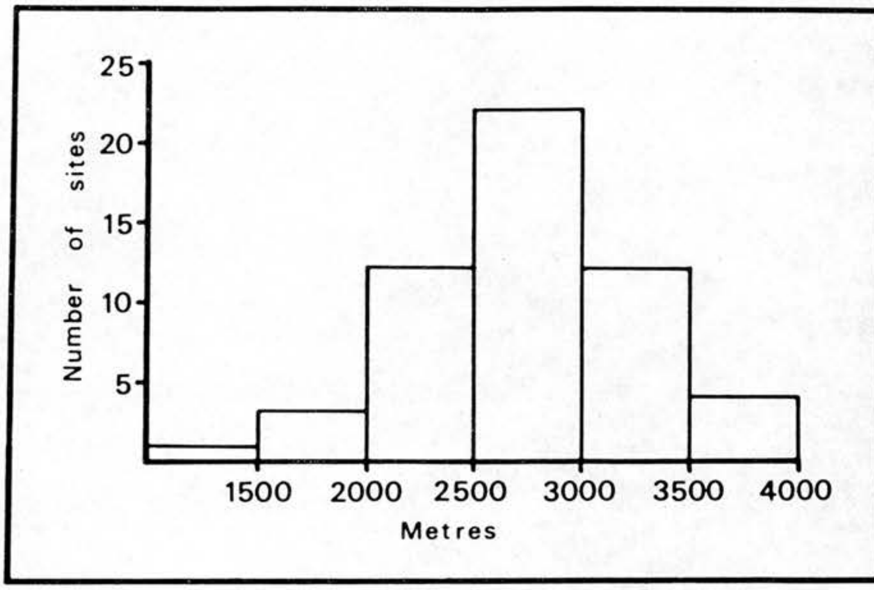


Figure 5.8: Frequency distribution of leeward slope (54 sites).

approximately normal in shape, with a skewness of -0.190 and kurtosis of 0.026.

Sites with low values include Allt Coire Dhondail (8) (1369m), Allt Fuaran Diotach (6) (1694m) and Allt a' Chram-alltain (2) (1700m). Sites with high values include 29 and 30 on Derry Cairngorm (both 3737m), Allt Iar-choire Sneachdach (33) (3612m) and Allt Toul (26) (3606m). Before reaching sites on Derry Cairngorm, winds from the east must pass over the often steep lee slopes of Carn Eas, Beinn a' Bhuird and Beinn Bhreac, while winds from the west must pass over the steep headwalls of Cairn Toul and Ben Macdui. The probability of snow being depleted before reaching these two sites would appear to be higher than that for sites with low values.

5.2.10 Snowdrift

Snowdrift is the relative amount of snow which would be deposited at a site on the basis of wind direction and the aspect of the site (see section 4.5). Although the mean value of 30 winters for each site was used in the analysis, the values of each winter are listed in Appendix 5. The measurement of snowdrift has five limitations.

1. Records from stations at low altitudes were used to calculate the precipitation on any day. Increases in precipitation with altitude are not directly incorporated, although the inclusion of top altitude and topographic rise in the analysis allows gradients of precipitation and the orographic increase in precipitation to be considered indirectly. No data on the amount of precipitation at individual sites were available.

2. The definition of snowdrift assumes that snow is deposited only on leeward slopes. Although this assumption was necessary for the calculation of snowdrift (no data exist on the proportion of snow deposited on leeward and windward slopes), in practice it is inaccurate as some snow will always be deposited on windward slopes.

3. Snowdrift was calculated at the source of each stream on the assumption that the leeward directions at the source would hold constant for the length of the gully. This assumption can be supported most readily for gullies located on exposed slopes (see section 5.2.2), where there are no further lee slopes within the basin. In deeply incised basins this may not always hold true. Allt Coire Fionn (38), for example, lies in a deep basin with the slopes of Meall Odhar forming the western boundary and the ridge

running to Sron na Gaoithe forming the eastern boundary. The basin itself is leeward to winds from the west, south and east, but the source of the gully is leeward to winds from the SW and SE only. As a result, snowdrift to the gully may be underestimated, particularly in its lower reaches. Other examples include Allt a' Mharcaidh (1), Beanaidh Bheag (11), Alltan na Beinne (35), Allt Clais Mhor (43) and Allt a' Gharbh-choire (39).

4. Over a period of 30 winters, snowdrift can vary considerably from winter to winter depending upon the frequency of winds and the occurrence of snowfall. Although a mean value is used, values for particular winters may have higher or lower correlations with the other variables. This point is acknowledged in Chapter 7 where the appropriate seasonal values for snowdrift (and wind-drift) are used in the regression analyses.

5. The final limitation is that of mid-season thaws which can remove the pattern of snowcover produced by earlier snowdrift. The characteristics of snowdrift after a thaw may be very different from that before. Owing to the lack of data on the drifting of snow and on the actual pattern of drifting in basins, these limitations cannot be overcome. Later studies may, however, try to correct them on the basis of more data and greater knowledge.

The mean value of snowdrift is 51.8% with a standard deviation of 11.6%, giving a coefficient of variation of 22.4%. Figure 5.9 shows the frequency distribution which is approximately normal with a skewness of 0.055 and kurtosis of -0.219.

Variation in snowdrift to each site for the 30 winters can be examined by calculating the mean and standard deviation for each site (see Appendix 5). The mean values are those used in the full analysis. The standard deviations range from 11.6% to 17.1% which

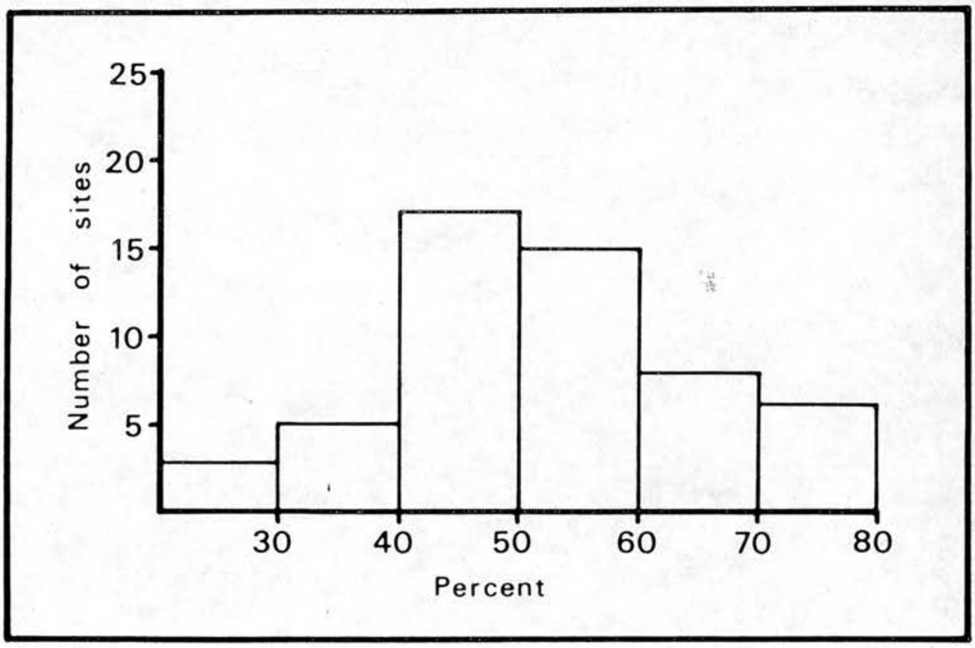


Figure 5.9: Frequency distribution of snowdrift (54 sites).

is remarkable in view of the range of mean values from 26.1% to 75.2%. This implies that there are no dominant wind directions in a winter and that sites with high average values of snowdrift have csistently high values each winter (and similarly for sites with low values).

5.2.11 Wind-drift

Wind-drift is the percentage of the total amount of deposited snow which will be redistributed by the wind on the basis of wind speed and direction, and the direction of fetch (see section

4.6). The values for each winter are listed in Appendix 6.

The procedure has three limitations. Two are identical to (4) and (5) in the section on snowdrift. The third limitation is that although three requirements were used to identify days on which wind-drift was assumed to occur, there is little evidence to confirm whether or not wind-drift actually occurred on those days. Fieldwork during the winters of 1982/3 and 1983/4, however, suggested that the requirements were quite successful (section 4.6).

The mean value of wind-drift is 44.8% with a standard deviation of 20.5%, giving a coefficient of variation of 45.8%. Figure 5.10 shows the frequency distribution which has minimal skewness (0.110), but moderate kurtosis of -0.736.

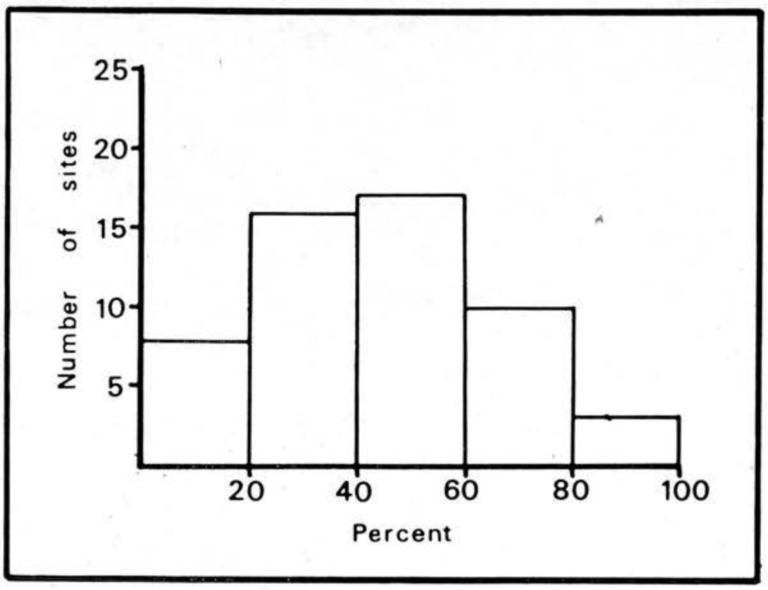


Figure 5.10: Frequency distribution of wind-drift (54 sites).

The individual values for each site over the 30 winters have standard deviations ranging from 10.2% to 24.8%, which are considerably higher than those for snowdrift (5.2.9). This greater variability is a product of the dominance of winds from one or two directions for wind-drift in any one winter (see Table 4.11).

The Feith Buidhe (17) (85.2%), Allt Fuaran Diotach (6) (81.9%), Allt Coolah (40) (81.8%) and Allt a' Choire Mhoir (23) (78.5%) have high values of wind-drift. These sites take advantage of fetch to the south, west and north, from which most wind-drift comes. Sites with low values include Beinn Mheadhoin (21), Allt Easan na Bruaich (10), Allt Coire an t-Sabhail (24), Allt Toul (26) and Allt Coire a' Chaisteil (46). These sites receive wind-drift from only one direction and have little fetch. All sites were assumed to receive some wind-drift, so sites with no measurable fetch were limited to wind-drift from one direction only.

5.2.12 Topographic exposure

Topographic exposure is the subtend of the contour at the mid-point of the gully. Although there were no problems with measurement, there is the problem, as with basin ratio, of how representative this value is of the gully as a whole. The basin may be more or less exposed above or below the mid-point. As the aim was to gain a relative value, however, the present method of measurement was deemed acceptable.

The mean value of topographic exposure is 107^{0} with a standard deviation of 43.2^{0}, giving a coefficient of variation of 40.2%.

Figure 5.11 shows the frequency distribution of the data. The data show minimal skewness (0.132) and a high value for kurtosis of -1.099.

Exposed sites have high values, where the contours run perpendicular to the line of the gully, e.g., Allt Easan na Bruaich (10), Allt Coire an t-Sabhail (24), Allt a' Mhaim (26), Derry Cairngorm (30), Allt Creag Dubh (19) and Beinn Mheadhoin (21) (all above 170^0). These sites tend also to have low values of form ratio and basin ratio.

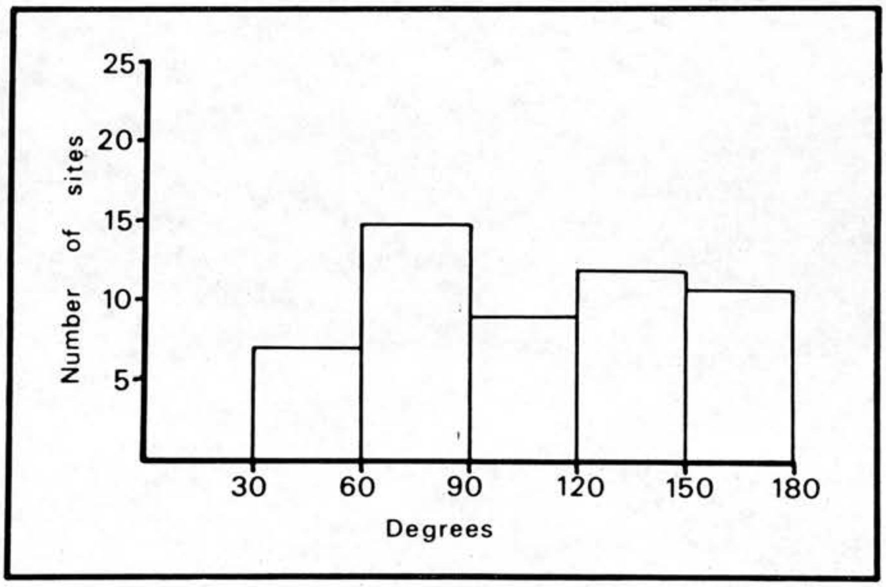


Figure 5.11: Frequency distribution of topographic exposure (54 sites).

Sites with incised basins have low values and include Allt Clais Mhor (43), Allt Coire a' Chaisteil (46), Allt a' Mharcaidh (1), Alltan na Beinne (35) and Allt Coire Ruairidh (36).

5.2.13 Summary

The definitions of all eleven variables have limitations and most have problems in their measurement. It is hoped that future work will try to improve the definition of the variables and reduce the problems associated with their measurement. Their influence on the accuracy of the method is discussed further in Chapters 7 and 8. Most of the data are distributed normally, so no transformations are required, except for the Pearsons Product Moment test and regression analyses.

5.3 REGIONAL DIFFERENCES IN THE MORPHOLOGY OF SITES

The sample of 54 sites used in this study was drawn randomly from the 180 sites located within the Cairngorm Mountains and the SE Grampian Highlands. The sample was composed of 40 sites from the Cairngorms and 14 sites from the SE Grampians. As the proportions in the population were 121 and 59 respectively, there was a mismatch of four sites (i.e., an "ideal" sample would have contained 36 and 18 sites respectively). When the sample was taken, it was assumed that both areas were part of the same population. In section 5.2.6 it was noted, however, that sites in the Cairngorms may be biased towards higher values of top altitude. This section will determine if real differences do exist between sites in the Cairngorms and those in the SE Grampians.

Table 5.2 shows the mean and standard deviation of each variable for sites in the Cairngorms and for sites in the SE Grampians. The table also shows the results of two statistical tests. The t-test was used to test the null hypothesis that the sites in the two areas were drawn from the same population. The null hypothesis was rejected for top altitude, topographic exposure and form ratio. This finding was confirmed by the results from a Univariate F-ratio test from the SPSS package (Nie et al., 1975) which can test the equality of the group means on each variable. For eight of the eleven variables, therefore, the two areas (or groups of sites) can be regarded as being part of the same population.

Table 5.2: Regional differences in the morphology of sites.Mean and standard deviations (S.D.), together with values and level of significance for the t-test (t) and univariate F-ratio (F).

	Cairngorms		Grampians					
	Mean	S.D.	Mean	S.D.	t	Sig.	F	Sig.
1	382.90	52.80	400.30	44.70	1.194	NS	1.21	NS
2	0.113	0.053	0.114	0.049	0.060	NS	0.00	NS
3	14.4	5.2	15.8	4.9	0.903	NS	0.83	NS
4	0.31	0.14	0.41	0.13	2.440	0.05	5.03	0.03
5	2049	1351	1650	819	1.305	NS	1.07	NS
6	998	102	877	50	5.310	0.001	17.96	0.001
7	960	144	988	36	1.134	NS	0.49	NS
8	2687	580	2818	296	1.082	NS	0.65	NS
9	51.2	12.1	53.5	10.5	0.680	NS	0.38	NS
10	45.9	21.0	41.6	19.5	0.690	NS	0.44	NS
11	117	42	78	35	3.390	0.01	9.62	0.003

1 Global radiation
2 Basin ratio
3 Gully side slope
4 Form ratio
5 Fetch
6 Top altitude
7 Topographic rise
8 Leeward slopes
9 Snowdrift
10 Wind-drift
11 Topographic exposure

The mean value of top altitude for sites in the Cairngorms is 998m, which is 121m higher than the mean value of 887m for sites in the SE Grampians. Inspection of the data in Appendix 7 shows that this difference is based on the absence of sites with high values of top altitude in the SE Grampians. To a limited extent this is because there were no sites in the sample from Lochnagar, the highest mountain in the SE Grampians, although only five sites have values of more than 1000m (maximum is 1084m) on Lochnagar, and only two other sites exceed 1000m in the SE Grampians. There are 51 such sites in the Cairngorms, a finding which confirms that the difference is real. A larger sample of sites from the SE Grampians would not alter this owing to the absence of sites with high values of top altitude.

Topographic exposure appears to be significantly different between the two areas, the mean exposure of sites in the Cairngorms being 117^0, and 78^0 for sites in the SE Grampians. As incised basins have low topographic exposure, this result suggests that, on the whole, sites in the SE Grampians are more incised than those in the Cairngorms. This point is confirmed by the values of form ratio. Sites in the SE Grampians tend to have higher values of form ratio than those in the Cairngorms. Analysis of OS maps at the scale of 1:25,000 confirms that there are few sites in the SE Grampians with low form ratio and high topographic exposure.

A possible cause of the differences between sites in the two areas on topographic exposure and form ratio could be the relatively small number of sites sampled from the SE Grampians. An "ideal" sample should show constant variability after a certain number of sites have been sampled. This can be checked by calculating the change in the standard deviation as each site is added to the total. Figure 5.12 shows this for sites in the Cairngorms and those in the SE Grampians for top altitude, topographic rise and form ratio. The variability for sites in the Cairngorms appears to become constant when the sample size reaches approximately 30 sites. The corresponding graphs for sites in the SE Grampians show that, for topographic exposure and form ratio, the sample size is too small relative to the degree of variability inherent in the data. Top altitude appears quite constant with a sample size of seven sites (in marked contrast to that for the Cairngorms). The small sample size for the SE Grampians may be responsible, therefore, for the differences between the two areas on topographic exposure and form ratio. The consequences of this for the research are assessed later.

The nature of the differences between the two areas can be assessed further using discriminant analysis. The technical details and assumptions behind discriminant analysis are described later (see section 6.4.1). Discriminant analysis is used here to assess the statistical significance of the a priori classification of the sites into the two groups. Discriminant analysis finds the linear combination of variables that discriminates best between the two groups, which can then be used to assess the accuracy of the classification. The SPSS "DISCRIMINANT" subprogram was used (Nie et al., 1975).

With an F-to-enter value of 5.0, three discriminant variables were identified: top altitude, topographic exposure and topographic rise. The last variable is anomalous in that its

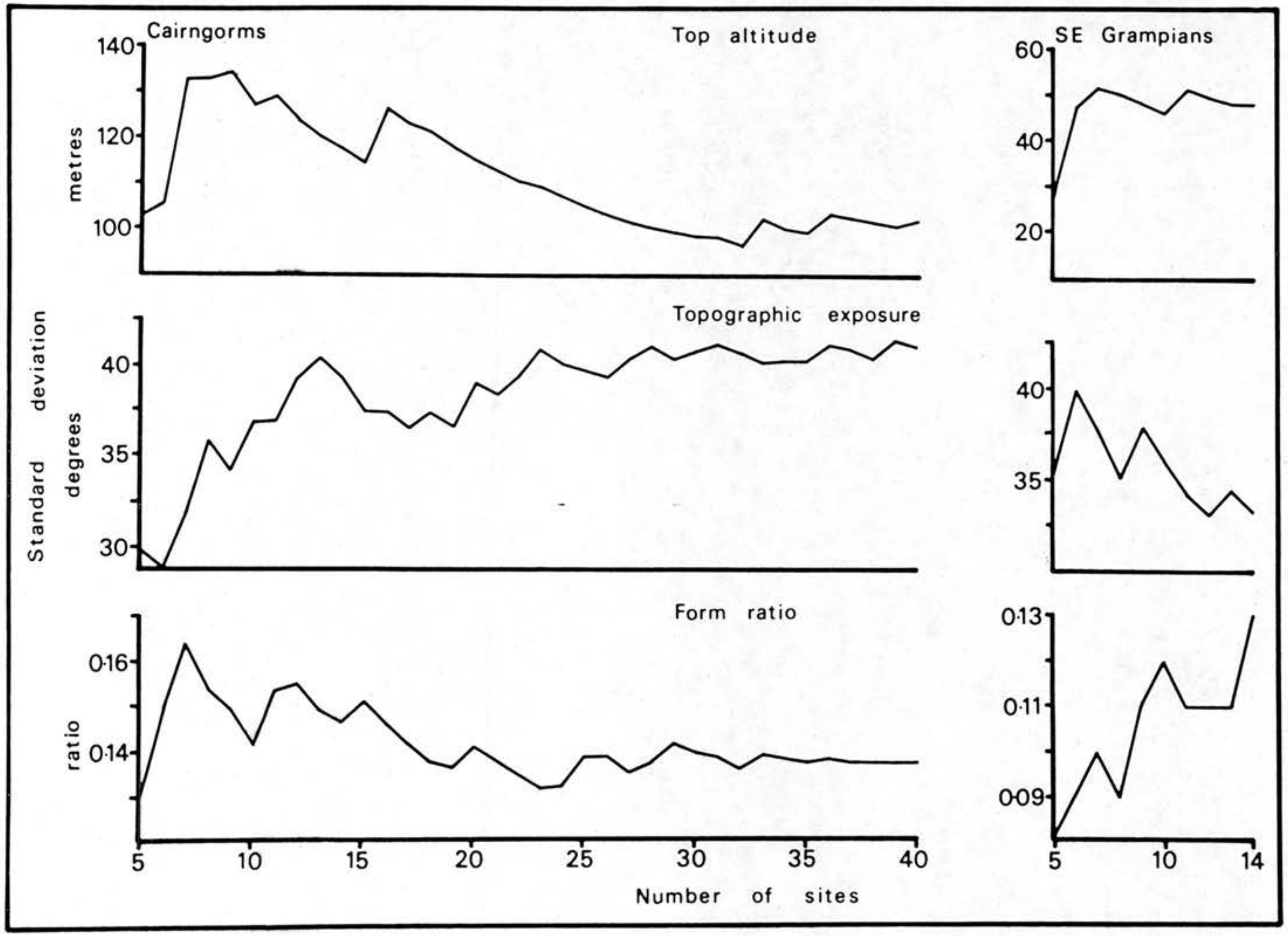


Figure 5.12: Variability of the standard deviation of top altitude, topographic exposure and form ration for sites in the Cairngorms and in the SE Grampians.

discriminant power appears to be linked in some way to the other two variables (see the results of the t-test in Table 5.2). Two Cairngorm and three SE Grampian sites were misclassified. If the only discriminant variable used is top altitude (F-to-enter value of 12.0), three Cairngorm and seven SE Grampian sites are misclassified. The division between the two areas, therefore, may not be as distinct as was first intimated. Removal of top altitude, topographic rise and form ratio from the analysis produced a discriminant function with four variables (F-to-enter of 1.0): global radiation, gully side slope, fetch and snowdrift. One Cairngorm and twelve (of the fourteen) SE Grampian sites were misclassified. The null hypothesis that no discriminant power exists between the two groups could not be rejected (p = 0.278).

Although the means of top altitude, topographic exposure and form ratio for the two groups of sites are quite different, almost all of the values for sites in the SE Grampians fall within the range of values present for sites in the Cairngorms. The difference between the two areas appears to be that the probability of sites in the Cairngorms having higher values of top altitude or topographic exposure or low values of form ratio is much higher than for sites in the SE Grampians. A further cause of the difference may be the small sample size for the SE Grampians. It should be remembered, however, that for most of the variables there are no significant differences between the two areas and they can be regarded as coming from the same population.

One final test for differences between the two groups is to calculate the 95% confidence intervals for the mean of each variable. If no differences exist then there should be overlap between the intervals of the two groups. Table 5.3 shows the

Table 5.3: 95% confidence intervals for the mean of each variable

	Cairngorms		SE Grampians	
	Lower	Upper	Lower	Upper
Global radiation	366.03	399.77	374.50	426.10
Basin ratio	0.096	0.130	0.086	0.142
Gully side slope	12.7	16.1	13.0	18.6
Form ratio	0.265	0.355	0.335	0.485
Fetch	1617	2481	1177	2123
Top altitude	965	1031	848	916
Topographic rise	914	1006	967	1009
Leeward slope	2502	2872	2647	2989
Snowdrift	47.3	55.1	47.4	59.6
Wind-drift	39.2	52.6	30.3	52.9
Topographic exposure	103	130	58	98

confidence intervals for all eleven variables. In 95 out of every 100 samples taken from the population, the mean would be expected to fall within these intervals. There is no overlap between the two groups on top altitude or topographic exposure, but one does exist on form ratio.

On two of the eleven variables, top altitude and topographic exposure, the Cairngorms and the SE Grampians can be regarded as separate populations. Given more time, the size of the sample from the SE Grampians could be increased to 30 sites (i.e., the assumed level of stability) and the multivariate analysis of the morphology of sites undertaken for both samples (i.e., treating them as separate populations). Increasing the size of the sample from the SE Grampians, however, would not alter the results of the t-test for top altitude, but may reduce the value of t for topographic rise and form ratio. If the two areas are treated as a single population, a sample of 25 to 30 sites would mean that sites with low values of top altitude would be over-represented. If they are treated as separate populations, the ability to compare sites between the two areas would be lost. If the two areas are kept together as one sample, the opportunity is retained to determine if the differences in top altitude and topographic rise are offset by the values of other variables at particular sites.

The influence of these findings on the statistical analysis to be presented in Chapters 6 to 8 is threefold:

1. the classification of sites using cluster analysis (6.3) may divide the sites into two main groups, i.e., Cairngorms and SE Grampians;

2. the calculation of predictive equations (e.g., discriminant functions, regression equations to predict component scores for any site) in Chapters 6 and 8, may be biased towards sites in the Cairngorms and be largely inapplicable to sites in the SE Grampians; and

3. where a strong regional difference exists in the extent of snowcover, the regression equations in Chapter 7 may simply identify top altitude, topographic exposure and form ratio as the regressor variables because of their spatial distribution.

In view of the aims of this thesis, which were to develop a method for the measurement of the natural potential of sites for downhill skiing (which could then be applied by others to satisfy their own aims) and to assess the application of the method, the present sample was considered to be satisfactory, provided the potential effects of the differences are noted. It is recommended, however, that future research apply the method to samples from each area, and compare the results with those in this thesis.

5.4 RELATIONSHIPS BETWEEN THE VARIABLES

In Chapter 3, the consistency of snowcover at different sites was hypothesised to be the product of the spatial relationships between the variables (that represent the processes that control the consistency of snowcover). A site with high top altitude and low global radiation, for example, should have more consistent snowcover than a site with low top altitude and high global radiation (all other things being equal). This section will attempt to determine which variables are strongly inter-related. The null hypothesis being tested is that the correlation between any two variables is zero, i.e., that each variable has an independent spatial distribution.

Pearson's Product Moment Correlation Coefficient (r) was used to test this null hypothesis. The correlation matrix was calculated using the SPSS "PEARSON CORRELATION" routine (Nie et al., 1975). Basin ratio and top altitude showed significant skewness and were transformed to a more normal distribution using a square root transformation.

Table 5.4 shows the correlation matrix for the eleven variables. Of the 55 coefficients, only 16 are significantly different from zero at the p = 0.05 level. (A coefficient of 0.23 is significant at the p = 0.05 level). The correlations between topographic exposure and basin ratio, gully side slope, form ratio, fetch, snowdrift and wind-drift are highly significant. As sites with high topographic exposure are located on exposed slopes where the contours of the slope are perpendicular to the gully, they tend to have low values of basin ratio and form ratio. These sites also seem to have low values of gully side slope, with a correlation of -0.46. The relationship also occurs at sites with low topographic exposure and steep side slopes, e.g., Allt a' Choire Ghuirm (32), Alltan na Beinne (35), Allt Coire Ruairidh (36), Allt Clais Mhor (43) and Allt Coire a' Chaisteil (46). The sources of streams with high exposure tend to be located well down the slope of the mountain, so these sites do not have long fetch. This explains the correlation of -0.44 between topographic exposure and fetch.

Form ratio has a positive correlation with fetch of 0.36, and is negatively correlated with topographic exposure (-0.42), because gullies located on exposed slopes tend to be narrow relative to their length (see section 5.2.4). Form ratio has relatively high correlations with snowdrift (0.30) and wind-drift

Global radiation	1.00										
Basin ratio	0.17	1.00									
Gully side slope	-0.08	0.24	1.00								
Form ratio	-0.05	0.22	0.20	1.00							
Fetch	0.14	0.21	0.08	0.36	1.00						
Top altitude	-0.01	-0.02	-0.15	-0.14	0.26	1.00					
Topographic rise	0.12	0.10	-0.15	0.06	-0.06	0.33	1.00				
Leeward slope	0.19	-0.01	-0.06	-0.24	-0.15	-0.14	0.15	1.00			
Snowdrift	-0.22	0.05	0.01	0.30	0.13	-0.09	-0.25	-0.06	1.00		
Wind-drift	0.07	0.14	-0.05	0.40	0.66	0.15	-0.18	-0.02	0.36	1.00	
Topographic exposure	-0.18	-0.52	-0.46	-0.42	-0.44	0.14	0.21	0.04	-0.27	-0.24	1.00

Table 5.4: Pearson Product Moment Correlation matrix of the eleven variables (54 sites).

(0.40). This finding has two implications:

1. sites with high values of form ratio tend to face west or east, or to be leeward to several wind directions, and hence receive more snow than other sites; and

2. although sites with high values of form ratio may trap snow before it reaches the gully, these sites tend to receive larger proportions of drifting snow, which may mitigate the adverse influence of high form ratio.

Basin ratio is positively correlated (0.24) with gully side slope, and suggests a weak tendency for deep, incised basins to have steep gully side slopes. The highest correlation (0.66) is between fetch and wind-drift. This correlation appears logical because a long fetch is likely to cover more wind directions than a shorter fetch. It could also imply that sites with long fetch have a tendency for the greatest length to be between SSE and WNW, for which wind-drift is greatest.

There is a tendency for sites with high (low) values of snowdrift to have high (low) values of wind-drift. Examples of this include Allt a' Choire Odhair (7), Feith Buidhe (17), Allt Easan na Bruaich (10), Allt a' Choire Ghuirm (32) and Buidheannach Burn (51).

The most important group of inter-related variables is that representing the morphology of gullies and basins, and in particular the correlations between topographic exposure and basin ratio, form ratio and gully side slope. These relationships suggest that two basic types of site exist:

1. sites with wide, deep basins, and

2. sites with very shallow and exposed basins.

This finding implies that the size and shape of basins may play an important role in controlling the consistency of snowcover at the sites. The absence of significant correlations (with several exceptions, notably topographic exposure and fetch) between the three main processes - supply, entrapment and retention - suggests that few sites will have good supply <u>and</u> entrapment <u>and</u> retention characteristics.

5.5 CONCLUSIONS

1. The definitions of all the variables have limitations and most have problems in measurement. These may affect the accuracy of the results and any attempts to validate the results.

2. Most of the data show only slight or moderate skewness and kurtosis.

3. On eight of the variables, the sites in the Cairngorms and those in the SE Grampians can be regarded as coming from the same population. On top altitude and topographic rise, however, they are separate populations.

4. The relationships between the variables are generally weak.

5. The most important relationship points to the existence of two types of site. One with relatively deep and incised basins, and one with shallow and exposed basins.

CHAPTER 6: MULTIVARIATE ANALYSIS OF THE MORPHOLOGY OF SITES.

6.1 INTRODUCTION AND BACKGROUND

In Chapter Three, five processes that control the consistency of snowcover were identified and eleven variables were chosen to represent these processes. It was hypothesised that the site(s) with the most favourable combination of values on the variables would have the most consistent snowcover. This was shown to be equivalent to assessing the null hypothesis that each variable has an independent spatial distribution. Several groups of inter-related variables, or patterns, within the data were identified in Chapter Five.

The aim of this chapter is to apply the method described in Chapter Three to identify these patterns within the data and to interpret the results as measures of the natural potential of sites for downhill skiing. The validity of the results will be assessed in Chapter Seven.

Principal components analysis, cluster analysis and discriminant analysis have been widely used by geographers, but their application in research into snowcover, however, has been restricted largely to predicting the occurrence of avalanches. Discriminant analysis, for example, has been used to predict avalanche and no-avalanche situations (Bovis, 1976; Fohn et al., 1977; Obled and Good, 1980).

Anderson and West (1965) used PCA to analyse data from 163 snow courses in the central Sierra Nevada, California. Unfortunately, the component loadings were not presented and there was confusion over terminology, e.g., whether PCA or factor analysis was being used. Rawls and Jackson (1979) used factor analysis but gave no results. Cluster analysis and discriminant analysis were used to predict the location of drift and no-drift areas in an experimental watershed (0.41km^2) in Idaho. Little information was given, however, on the methods used and no dendrogram was presented. The discriminant functions classified 80% of the no-drift points and 83% of the drift points correctly. When used on a different set of data, the functions classified only 64% and 65% of the points correctly.

6.2 PRINCIPAL COMPONENTS ANALYSIS

6.2.1 Background

Principal components analysis (PCA) transforms a set of variables to a new set by locating each new variable in vector space by its correlations with the original variables. The new variables, or components, have the following features:

1. each is a linear combination of the original variables (i.e., the first component is the "best" combination of all possible correlations between the variables in vector space);
2. they are independent (orthogonal) of each other; and
3. the first component accounts for the greatest variance, the second component accounts for the greatest variance among the residual, and so on.

The first principal component is the most important pattern within the data, located in vector space by its correlations with the other variables. Each of the original variables has a loading on each component, which is equivalent to the correlation between the variable and the component. The sum of the squared loadings indicates the total variance accounted for by the component and is known as the eigenvalue. Each site has a score on each component, which reflects its values on the original variables and the loadings of the variables on the components.

If a group of variables which are strongly correlated exist, that group will be represented strongly on the first component. The loadings of these variables on the component will be high and the eigenvalue will be high. Variables that are not correlated with this group will have low loadings on this component. Sites that are associated strongly with this group of variables will have high positive or high negative scores on the component. If global radiation (negative) and top altitude (positive), for example, had high loadings on the component, sites with low global radiation and high top altitude would have high positive scores and sites with high global radiation and low top altitude would have high negative scores.

The aim in using PCA in this research is to determine if any general patterns exist within the data which may reflect particular advantages or disadvantages as to the consistency of snowcover at sites. If the loadings of the original variables on each component are unambiguous, physical interpretation of them is possible. The component scores can then be interpreted as relative measures of the natural potential of each site (i.e., the sixth step in Table 2.6).

Although Marriott (1975, p.18) suggested that data need not be normally distributed for use in PCA, severe skewness or kurtosis may affect the results because the components are derived from a correlation matrix. As skewness and kurtosis are largely not significant, however, for the data being used, no transformations were undertaken. The data must be standardised, however, if different units of measurement have been used.

A version of program 7.10 in Davis (1973), modified for use at the Edinburgh Regional Computing Centre (by Mr. A. J. Alexander) was used. The program standardizes the data.

To verify the accuracy of the results, the SPSS "FACTOR" subprogram (type PA2 - principal factoring with iteration) (Nie et al., 1975) was run on the same data. The results were identical to those produced by the Davis program.

There are two problems with PCA which must be considered. First, the number of sites should considerably exceed the number of variables, particularly when the principal components are to be used in a regression anlysis, where the degrees of freedom have to calculated (Morgan, 1978). In the present study, however, this is not a problem, except that it precludes the use of PCA on a separate matrix of the 14 sites in the SE Grampians (see section 5.3). The second problem is that the choice of variables influences the results of a PCA (Dowdeswell, 1982). The first principal component in Dowdeswell's analysis is weighted "..towards relative weathering rather than lichenometric evidence simply because 10 of the 13 original varibles concern the former.." (p.155). If seven of the eleven variables in this study, for example, represented the retention of snow, the first principal component would be biased towards the retention of snow. This was the reason for the removal of gully depth from the analysis in Chapter 3.

6.2.2 Analysis of the results

The eigenvalues of the first five components, together with individual and cumulative percentages of the total variance, and the loadings of the original variables, are listed in Table 6.1. All component scores are listed in Appendix 9. As a loading of 0.50 means that only 25% of the variance of that variable is accounted for by that component, the relative, rather than the absolute, strength of the loadings will be important.

The first principal component accounts for 25.2% of the variance in the original data and represents the most important

Table 6.1: Eigenvalues, percent explanation and loadings for the principal component analysis of the 54 site by 11 variable matrix listed in Appendix 7.

Component	1	2	3	4	5
Eigenvalue	2.771	1.665	1.518	1.172	0.946
% of trace	25.2	15.1	13.8	10.7	8.6
Cum. % of trace	25.2	40.3	54.1	64.8	73.4
Global radiation	0.047	0.131	0.586	0.317	0.113
Basin ratio	0.298	-0.163	0.424	-0.045	0.139
Gully side slope	0.240	-0.389	0.167	-0.359	-0.104
Form ratio	0.405	0.042	-0.099	-0.148	-0.526
Fetch	0.420	0.392	0.047	0.029	0.175
Top altitude	-0.026	0.573	0.056	-0.337	0.200
Topographic rise	-0.188	0.378	0.264	-0.292	-0.638
Leeward slopes	-0.155	-0.029	0.282	0.597	-0.377
Snowdrift	0.278	-0.053	-0.453	0.265	-0.241
Wind-drift	0.396	0.366	-0.158	0.334	0.054
Top. exposure	-0.466	0.202	-0.234	0.095	0.020

pattern. Topographic exposure (-0.466), fetch (0.420), form ratio (0.405) and wind-drift (0.396) all have relatively high loadings. Basin ratio and snowdrift have moderate loadings. These loadings indicate that sites with low topographic exposure tend to have long fetch and high values of form ratio and wind-drift. Equally, sites with high topographic exposure tend to have low fetch and form ratio. This result supports the conclusions of Chapter 5 for two main reasons.

1. Sites with high topographic exposure tend to be located on exposed slopes, and so the the basins are narrow relative to their length (i.e., low form ratio). The source of each stream tends to be located well down the slope of the mountain, so fetch is minimal.

2. Sites with low topographic exposure have incised basins which tend to be wide relative to their length (i.e., high form ratio). Some of these sites drain the summit plateaux of the Cairngorm Mountains and the SE Grampian Highlands, and so have long fetch.

Interpretation of the component is aided by looking at those sites with high and low scores. Table 6.2 shows the characteristics of the four sites with the highest scores on the component, while Table 6.3 shows the characteristics of the four sites with the lowest scores. The mean value of each variable is also given. Sites with high scores, e.g., site 31, tend to have average or below average topographic exposure, and well above

Table 6.2: Sites with the highest scores on the first principal component.

Site Score	31 3.305	7 2.811	6 2.046	4 2.000	 Mean
Top. exposure (degrees)	82	110	130	72	107
Fetch (metres)	5850	2650	2575	3575	1946
Form ratio	0.58	0.54	0.47	0.36	0.334
Wind-drift (%)	70.0	79.5	81.9	55.1	44.8

Table 6.3: Sites with the lowest scores on the first principal component.

Site Score	10 -3.706	51 -3.219	26 -2.968	25 -2.769	 Mean
Top. exposure (degrees)	176	157	180	162	107
Fetch (metres)	0	375	0	0	1946
Form ratio	0.11	0.15	0.15	0.21	0.334
Wind-drift (%)	19.6	14.7	27.9	18.2	44.8

average values of fetch, form ratio and wind-drift. The clearest evidence for the two types of sites are those with low scores. Table 6.3 shows that these sites have very high values of topographic exposure, and well below average values for fetch, form ratio and wind-drift.

Interpretation of component scores should be done with care, however, for site 4 (Table 6.2) has an average form ratio and relatively low wind-drift. The high score is a product of a well below average value of topographic exposure and long fetch. A high score (or a low one) does not, therefore, automatically mean that that site will score "well" or "badly" on all variables with high loadings on that component.

The usefulness of scores on the principal components as measures of natural potential is supported by the finding that some sites with very low topographic exposure, e.g., Allt a' Mharcaidh (1), Alltan na Beinne (35), Allt Coire Ruaraidh (36), Allt Clais Mhor (43) and Allt Coire an Chaisteil (46), do not have the highest scores on the first component. For a variety of reasons, the potential advantage reflected by low exposure is mitigated by low values of fetch and wind-drift. Sites with the highest scores have the best combination of values on the four variables and, therefore, have the best combination of basin incision and wind-drift.

With the exception of fetch and wind-drift, the component is related more to the entrapment of snow than its retention or supply. Increased topographic incision will create turbulence in the air that induces the erosion of snow on windward slopes and deposition on leeward slopes. There is some evidence to suggest, however, that this will also increase the rate of melt during warm, windy weather through turbulent exchange (section 3.2.4). Figure 6.1 shows the two basic types of site identified by this component. Type A is relatively deep and incised, so that the basin, rather than the gully, is the dominant topographic feature of the site. The efficiency of the gully in the entrapment of

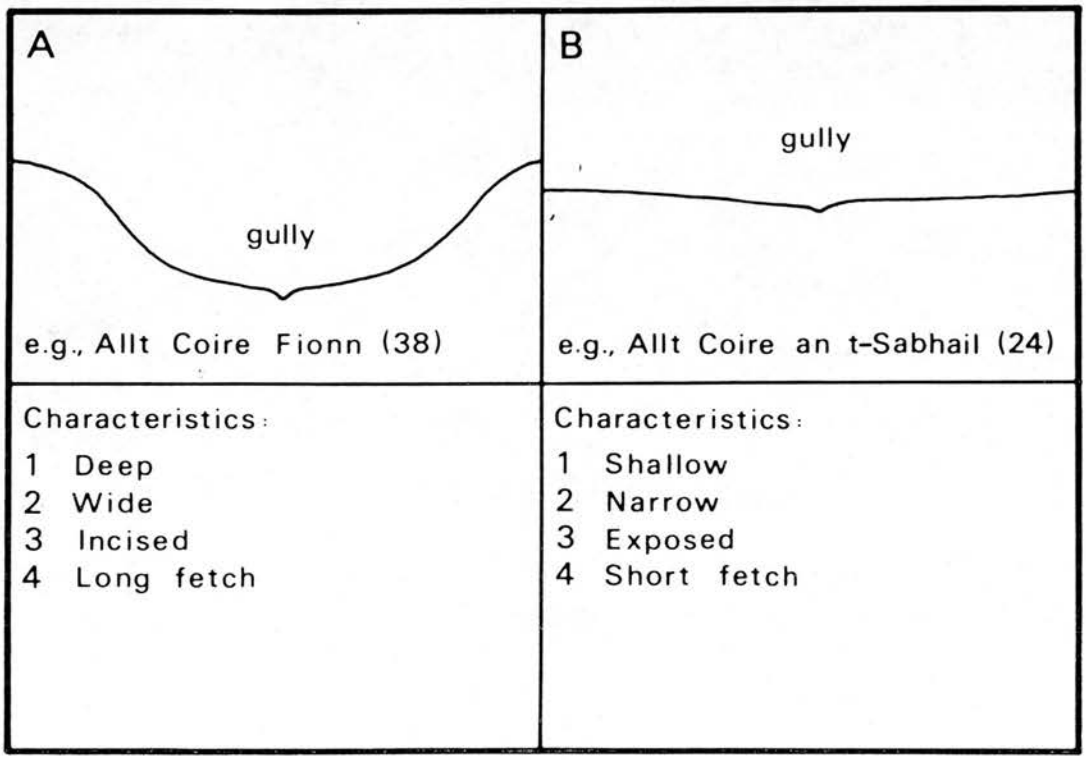


Figure6.1: Two types of site identified from the first principal component.

snow will be reduced, while the efficiency of the basin will be high. Snow may be trapped on steep headwalls within the basin. Plate 4 shows the relatively deep basin of Allt Choire Chais (15). A snowfield which has survived since the winter can be seen on the steep headwall ("1" on the Plate). The gully can be traced to the right of the buildings and access road.

In Type B (Figure 6.1), the gully is the dominant feature of the basin and presents the main obstacle to winds perpendicular to it, so its efficiency in the entrapment of snow will be high. Although having limited fetch, the absence of any topographic obstacles on either side of the gully may lead to large amounts of snow being blown into the gully along its length. Plate 5 shows the exposed nature of Allt Buidheannach (9). Snow which has survived since the winter can be seen in the gully just below the skyline (altitude of 890m) and the absence of large topographic obstacles should be noted. Type A should, therefore, have a much larger and more consistent snowfield surrounding the gully than type B, although the latter may have deeper snow in the gully (this is confirmed by the two photographs).

The second principal component accounts for 15.1% of the variance (see Table 6.1). Top altitude has the highest loading (0.573), while fetch (0.392), gully side slope (-0.389), topographic rise (0.378) and wind-drift (0.366) all have relatively high loadings. These results suggest that sites with high values of top altitude tend to have long fetch, above average values of wind-drift and topographic rise, but low values of gully side slope. As noted in sections 5.2.6 and 5.2.7, sites with high values of top altitude drain the summit plateaux of the

Plate 4: Basin of Allt Choire Chais (15) taken on the 15.6.85.

Plate 5: Basin of Allt Buidheannach (9), taken on the 16.6.85.

Cairngorm Mountains and so have long fetch. Tables 6.4 and 6.5 show the characteristics of those sites with the highest and lowest scores on the component. The negative loading of gully side slope is most clearly seen for sites with low scores.

Table 6.4: Sites with the highest scores on the second principal component.

Site	23	22	17	8	
Score	3.455	3.176	2.524	2.348	Mean
Top altitude (metres)	1268	1232	1145	1208	966
Fetch (metres)	3625	3975	2700	2325	1946
Gully side slope (degrees)	17.1	12.5	11.5	16.5	14.8
Topographic rise (metres)	1227	1116	1046	1315	967

Table 6.5: Sites with the lowest scores on the second principal component.

Site	46	43	33	32	
Score	-3.292	-2.006	-1.784	-1.744	Mean
Top altitude (metres)	892	895	867	919	966
Fetch (metres)	875	300	350	1925	1946
Gully side slope (degrees)	27.2	21.3	21.3	21.5	14.8
Topographic rise (metres)	944	972	819	846	967

sites with low scores. These sites also have limited fetch and low values of topographic rise. Sites with high scores tend to have average values of gully side slope.

As with the first component, the exact influence of this combination of variables on the consistency of snowcover is a little unclear. To some extent, a low value of gully side slope is offset by above average values of top altitude and fetch at sites with high scores. Sites with low scores have steep gully side slopes but very low values of top altitude and fetch. Although sites with high scores have only average gully side slopes, the above average values of top altitude and fetch should mean that these sites have the most consistent snowcover, owing to better retention and supply characteristics.

The third principal component accounts for 13.8% of the variance. Global radiation (0.586), snowdrift (-0.453) and basin ratio (0.424) have relatively high loadings. As 61.3% of all snowdrift comes from the two southern quadrants (Table 4.9), sites facing NW or NE tend to receive more snowdrift (as they are leeward to winds from the SE and/or SW), and less global radiation than sites facing SE or SW. This explains the positive and negative loadings of global radiation and snowdrift respectively. There also appears to be a tendency for sites facing SW or SE to be more incised than those facing NW or NE (hence the positive loading for basin ratio).

Allt a' Choire Ghuirm (32) has a very high score (4.218) on this component, owing to well above average values of global radiation and basin ratio (see section 5.2.3) and below average snowdrift. Sites with low scores (7,14,15,19) have below average global radiation and basin ratio, but well above average snowdrift. Holding the influence of the other components constant, snowcover at sites with low scores should be more consistent owing to low values of global radiation and high values of snowdrift, although the influence of basin ratio (which would tend to be low at such sites) on the entrapment of snow may complicate the picture.

The fourth principal component accounts for 10.7% of the variance. Leeward slope has the highest loading (0.597), and gully side slope (-0.359), top altitude (-0.337), wind-drift (0.334) and global radiation (0.317) have moderate loadings.

Sites with high values of leeward slope tend to have low values of gully side slope and top altitude, and high values of wind-drift and global radiation. Apart from leeward slope, the loadings are, however, relatively small, so the component represents only a weak pattern within the data.

Two sites on Derry Cairngorm (29,30) have high scores on this component, owing to above average values of leeward slope (section 5.2.9), average values of global radiation and top altitude and well below average gully side slope. Other sites with high scores include Allt a' Mhaim (26), Allt Iar Choire an t-Sneachda (33), Allt Coire an t-Sneachda (34) and Allt Coolah (40). Sites with low scores include Allt Coire Dhondail (8), Allt Buidheannach (9), Allt Coire an Chaisteil (46), Allt a' Chram-alltain (2) and Allt Fhearnagan (3). These sites all have below average values of leeward slope and above average values of gully side slope.

The exact influence of leeward slope on the consistency of snowcover is a little unclear (see section 5.2.9), as a high value could comprise one long slope or several shorter slopes (see Figure 3.10). The latter case would create greater turbulence in the air than the former. A low score on the component, however, would appear to represent more consistent snowcover because of the above average values of gully side slope, although values of top altitude and global radiation vary considerably between these sites.

The fifth principal component accounts for only 8.6% of the variance. With an eigenvalue of 0.946, it explains less variance than any one of the original variables (each being equivalent to an eigenvalue of 1.0), but is sufficiently close to 1.0 to be consisdered. Topographic rise (-0.638), form ratio (-0.526) and leeward slope (-0.377) have the highest loadings, which suggest a relatively strong tendency for sites with low (high) values of topographic rise to have low (high) values of form ratio.

Sites with low scores have high values of topographic rise and form ratio, e.g., Allt a' Choire Mhoir (23), Allt a' Gharbh-choire (39), Allt Coire a' Bhuidhe Mhor (46). Sites with high scores have low values of topographic rise and form ratio, e.g., Allt Fhearnagan (3), Allt a' Choire Chais (15), Allt na Ciste (16) and Allt a' Choire Ghuirm (32).

Several groups of inter-related variables do exist within the data. Interpretation of the components is restricted, however, because the relationships between the variables are not causal and so are generally weak. As a consequence, the eigenvalues of the components and the loadings of the variables are low when compared with published work where the aim has been to identify causal relationships (e.g., Mather and Doornkamp, 1970; Mather, 1976; Morgan, 1978). The aim, however, was to assess the null hypothesis that each variable has an independent spatial distribution. There is no single group of strongly inter-related variables, although some meaningful relationships do exist such that the scores could be interpreted as measures of natural potential. The validity of the scores will be tested in Chapter 7. As some relationships exist, it is possible that some sites are similar to each other and can therefore be grouped together.

A plot of the scores on the first two components can provide evidence of any groups of sites which may exist in multidimensional space. Figure 6.2 shows the plot of the relevant scores. There appear to be several groups, the first of which is

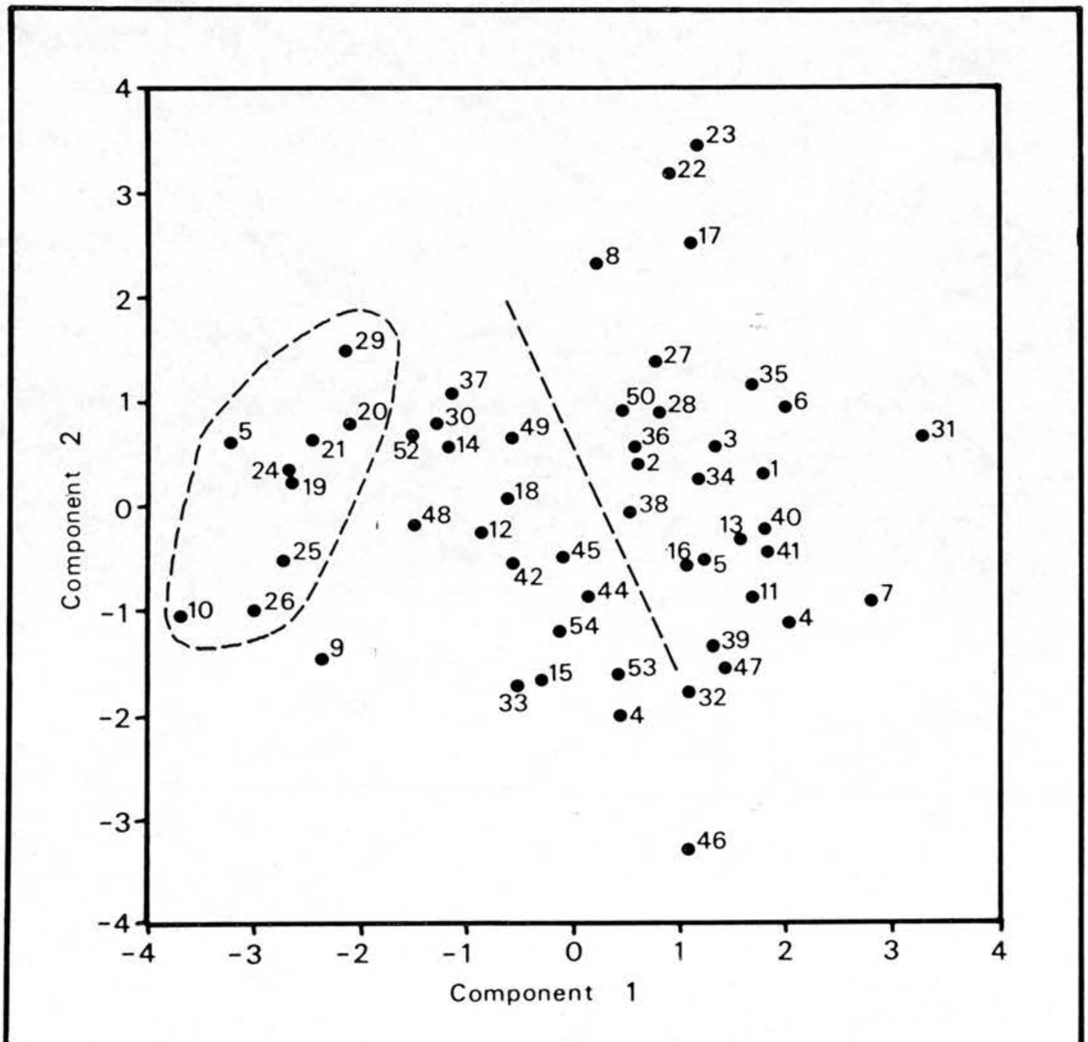


Figure 6.2: A plot of the scores on the first two principal components.

on the left side of the plot (marked on Figure 6.2). A second group of sites (8, 17, 22 and 23) have high scores on the second principal component. The remaining sites appear to occupy a single group, although it can be subdivided as illustrated by the dashed line in Figure 6.2. As only 40% of the total variance is accounted for by the first two components, however, three or four components may be required before distinct groups can be identified. This can be done more effectively using cluster analysis.

6.3 CLUSTER ANALYSIS

6.3.1 Background

Cluster analysis is used to identify groups of sites with similar characteristics on the variables measured, while the groups themselves are relatively distinct from one another. Cluster analysis is based on the proximity of points (sites) in multidimensional space, the distance between the points being a measure of the level of similarity (Davis, 1973). Interpretation of Figure 6.2 suggested that several groups may exist, so cluster analysis is used here to determine if these groups do exist. The resultant classification can be tested using discriminant analysis.

Although there are many clustering methods (see Wishart, 1978), three are commonly used (Davis, 1973):

1. weighted pair-group method (the "median" method);
2. error sum of squares ("Ward's" method), and
3. flexible strategy (Lance and Williams's "beta" method).

Full technical descriptions of these and other, less commonly used, methods are given by Davis (1973), Mather (1976) and Wishart (1978). The degree of similarity between sites in multidimensional space is measured usually in one of two ways.

First, the product moment correlation coefficient which measures the correlation between pairs of sites on the variables used. The pair of sites with the highest mutual correlation are grouped first, and so on until the pair with the lowest correlation has been grouped. Second, the Euclidean distance measure, which is:

$$D_{ij} = \sqrt{\frac{\sum(X_{ik} - X_{jk})^2}{m}}$$

where X(ik) is the kth component score on site i, X(jk) is the kth component score on site j, m is the number of components and D(ij) is the distance between sites i and j (Davis, 1973; p. 457). A set of four cluster analyses were undertaken:

1. Ward's method with a Euclidean distance measure;
2. Lance and Williams's flexible strategy with a Euclidean distance measure;
3. the median method with a similarity measure (the product moment correlation coefficient); and
4. the median method with a Euclidean distance measure.

All four analyses were undertaken using the routines available in the CLUSTAN package (Wishart, 1978). The CLUSTAN package also calculates the principal component scores for input into cluster analysis.

Data need not be normally distributed for use in cluster analysis (Marriott, 1975) although, as with PCA, severe skewness and kurtosis may affect the results. The data must be standardised, however, when different units of measurement have been used. One problem with cluster analysis (or with any classification) is the definition of a group or class. Groups can be of varying size and shape in multidimensional space. Indeed, in a hierarchical classification, all sites are eventually members of one group: in a 54 site matrix, there could be anything from 1 to 54 groups. The general consensus in the literature is that judgement is of particular importance (Davis, 1973; Johnston, 1980). Although the statistical significance of any classification can be tested using discriminant analysis, there remains the problem of whether the classification can be interpreted.

From the results in Chapter 5, and in section 6.2, it would be reasonable to expect that the first principal component would exert considerable influence on the classification. The dendrogram should show at least two clearly different groups: one related to sites that are deep and incised, and the other to sites that are located on exposed slopes. As the components are relatively weak, however, several groups may exist within the data.

6.3.2 Analysis of the results

Dendrograms produced from the four cluster analyses are shown in Figures 6.3 to 6.6. The first problem for interpretation is to decide how many groups exist. Figure 6.3 shows the dendrogram for "Ward's" method with a Euclidean distance measure. If a line is drawn across the dendrogram at 4.0, there are seven groups. If the line is drawn at 7.0 there are four groups. Below 4.0, the number of groups increases rapidly. The choice is largely subjective: less than seven groups would probably result in too much variation within a group, while more than seven creates the

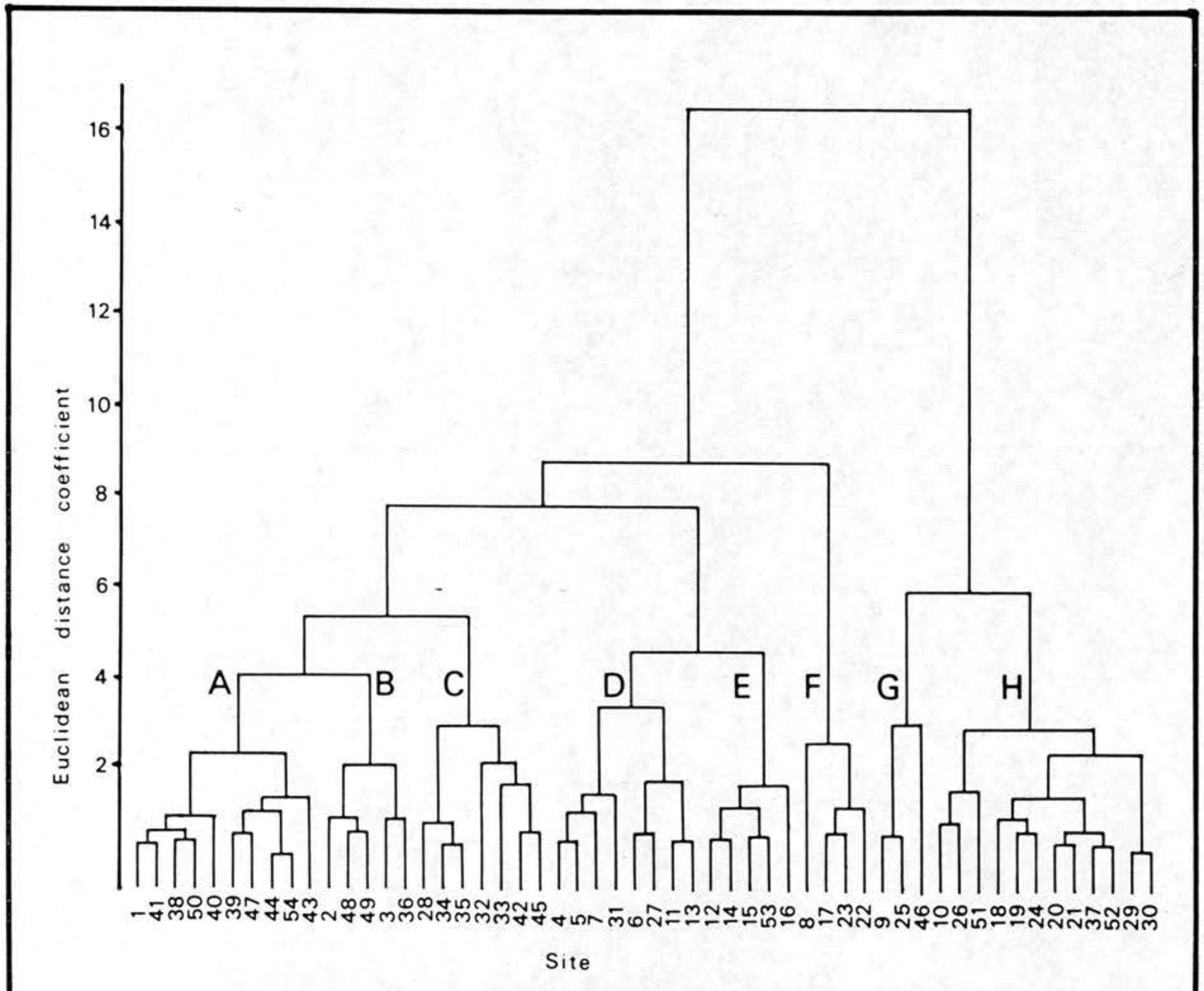


Figure 6.3: Dendrogram of the 54 sites using Ward's error sum of squares method.

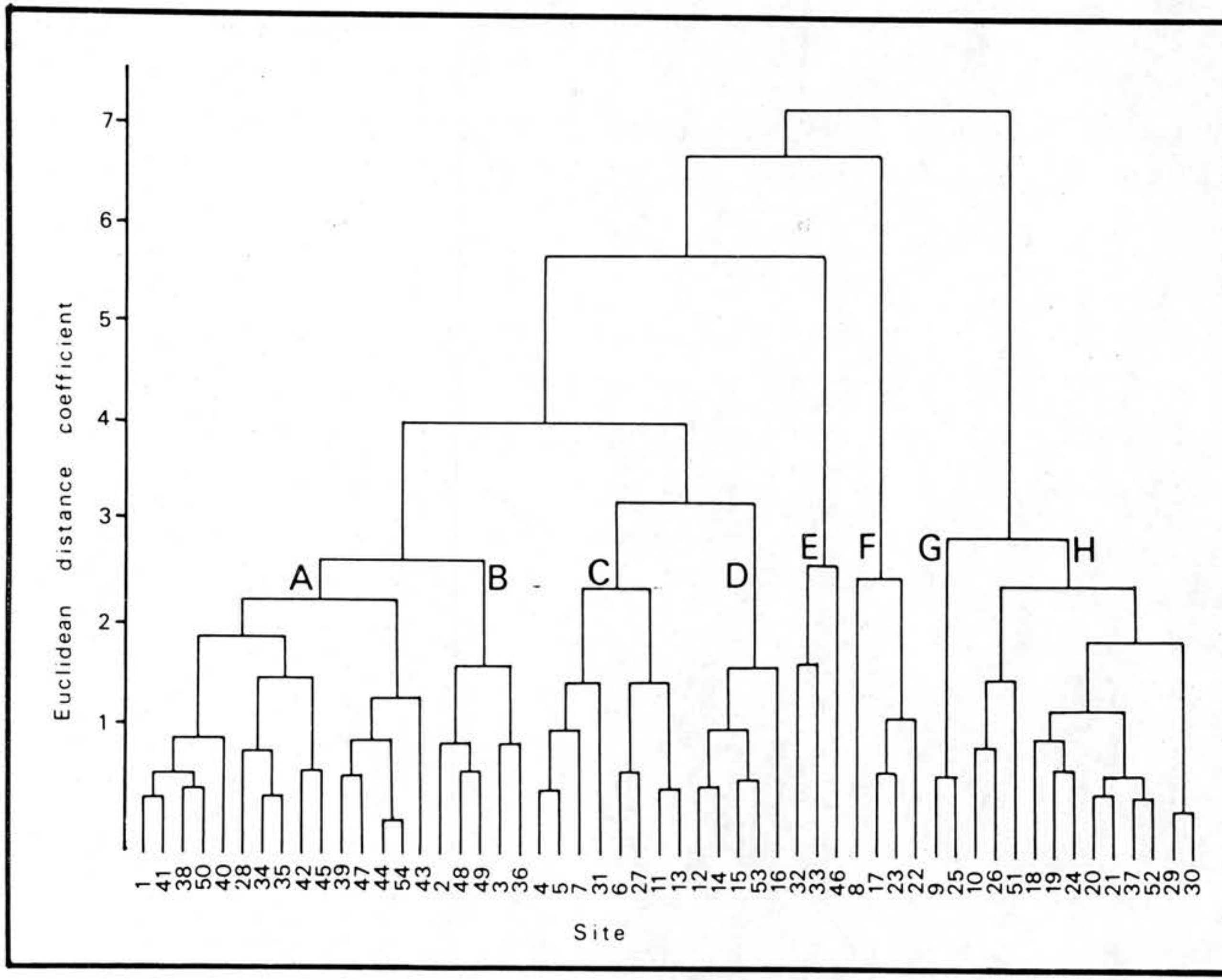


Figure6.4: Dendrogram of the 54 sites using Lance and Williams's beta method (beta = -0.25).

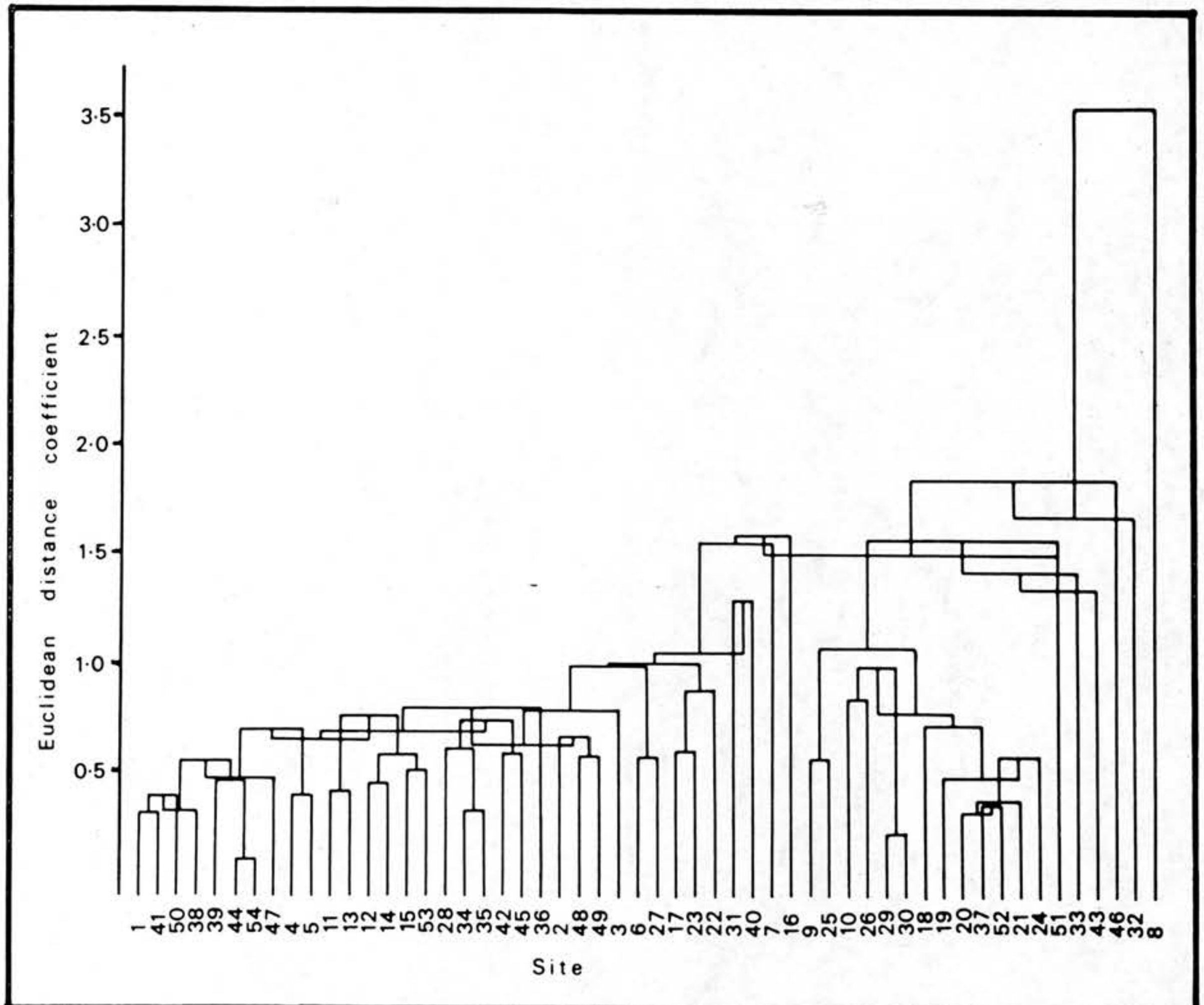


Figure 6.5: Dendrogram of the 54 sites using Gower's method with a Euclidean distance measure.

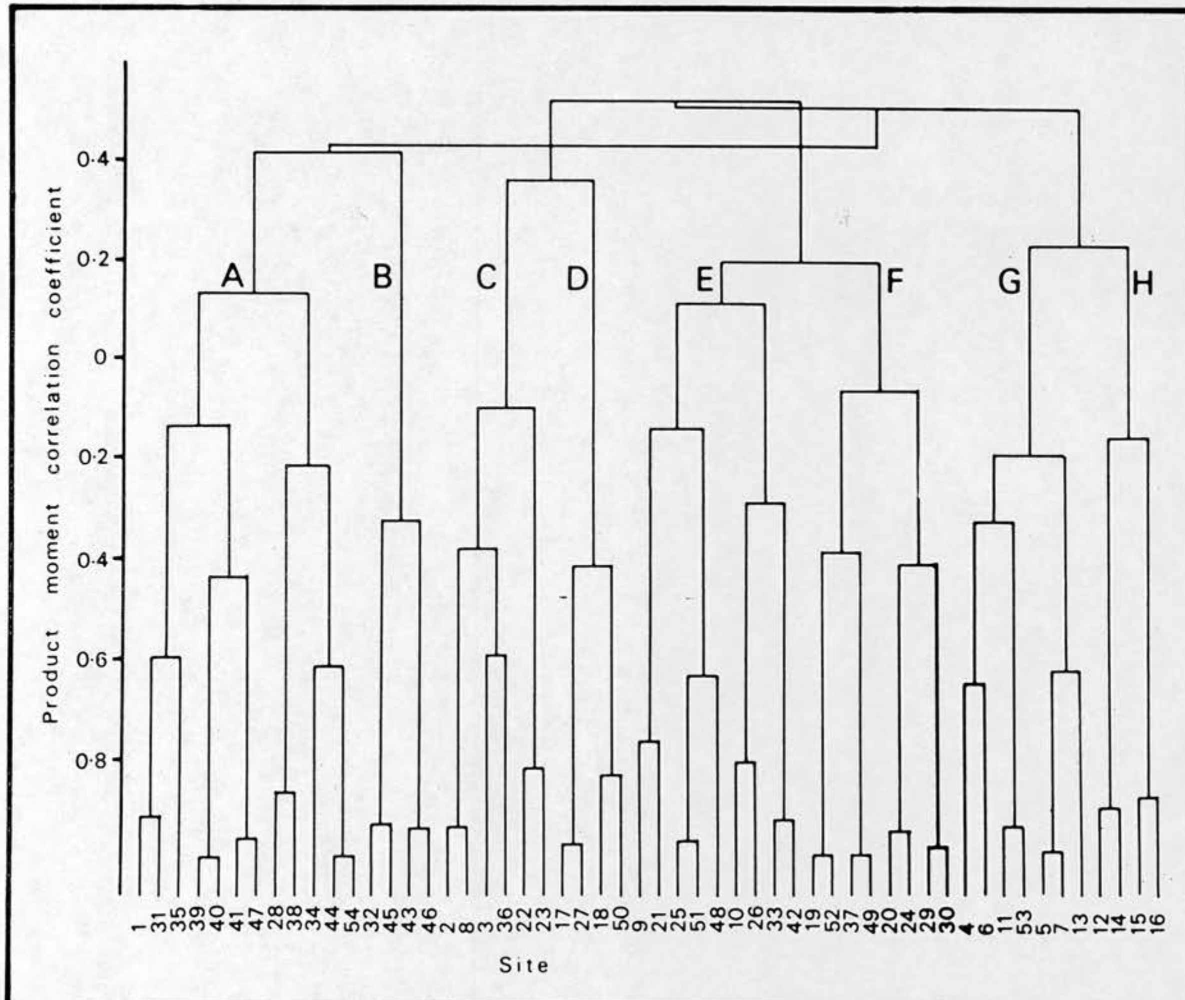


Figure 6.6: Dendrogram of the 54 sites using Gower's method with a similarity coefficient.

there being too many small groups, some of which may be essentially similar to one another. The groups are noted on each dendrogram.

The "best" classifications in terms of clarity are those produced by Ward's error sum of squares method and Lance and Williams's beta method. This finding agrees with that of Frenkel and Harrison (1974) who assessed several methods for the classification of vegetation communities. Wishart (1978, p.34) suggested that with a beta value of -0.25 (that used in this study), the Lance and Williams's method "...behaves much like Ward's method". Of the two measures used with Gower's median method, the correlation coefficient produces the "best" results. With a Euclidean distance measure, Gower's method produces chaining of the sites and a number of reversals (where the lines of the dendrogram cross over each other), a tendency which is noted by Wishart (1978, p.33). The classifcation produced using the median method with a Euclidean distance measure will not be analysed because of this.

In Figure 6.3 there are two very dissimilar groups with a Euclidean distance coefficient of 16.534. The influence of the first principal component is apparent as sites in group 7 and 8 are largely shallow, with low form ratio and limited fetch. This division is also apparent in the classification derived from the use of Lance and Williams's method (Figure 6.4). The groups are identical but for one exception: site 46 is found in group 7 in Figure 6.3 and in group 5 in Figure 6.4.

Overall, the alternative methods produce similar results. Table 6.6 lists those groups of sites identified by most or all

Table6.6: Groups of sites identified by all three methods and by at least two methods (in brackets).

I	1,38,39,40,41,44,47,54 (28,34,35,43,50)
II	12,14,15,16 (53)
III	10,19,20,21,24,26,29,30,37,51,52 (18)
IV	4,5,6,7,11,13,31 (27)
V	8,22,23 (17)
VI	32,33, (42,45)
VII	2,3,36 (48,49)
VIII	(9,25)

of the methods. Sites within each group should have similar supply, entrapment and retention characteristics, a point that will be examined later in this chapter. Two points can be made from an analysis of the groups in Table 6.6.

1. Sites in the SE Grampians do not form a wholly separate group. The 14 sites are found in three of the groups listed above, although nine of the sites are found in I. There is a tendency, therefore, for most sites in the SE Grampians to be grouped together, but with several sites from the Cairngorms. It can be concluded that the difference between sites in the Cairngorms and those in the SE Grampians is not the dominant feature in the data (i.e., the division between deep and shallow basins).

2. Some sites in close geographical proximity to each other are grouped together, e.g., 4,5,6 and 7; 12,14,15 and 16; 19,20 and 21; 22 and 23; 29 and 30; 38,39,40 and 41. Figure 6.7 shows the group membership of sites in a spatial context. Some geographical clustering is evident, which suggests that sites in close geographical proximity to each other have similar supply, entrapment and retention characteristics (see section 6.5).

The classification produced by the Lance and Williams's beta

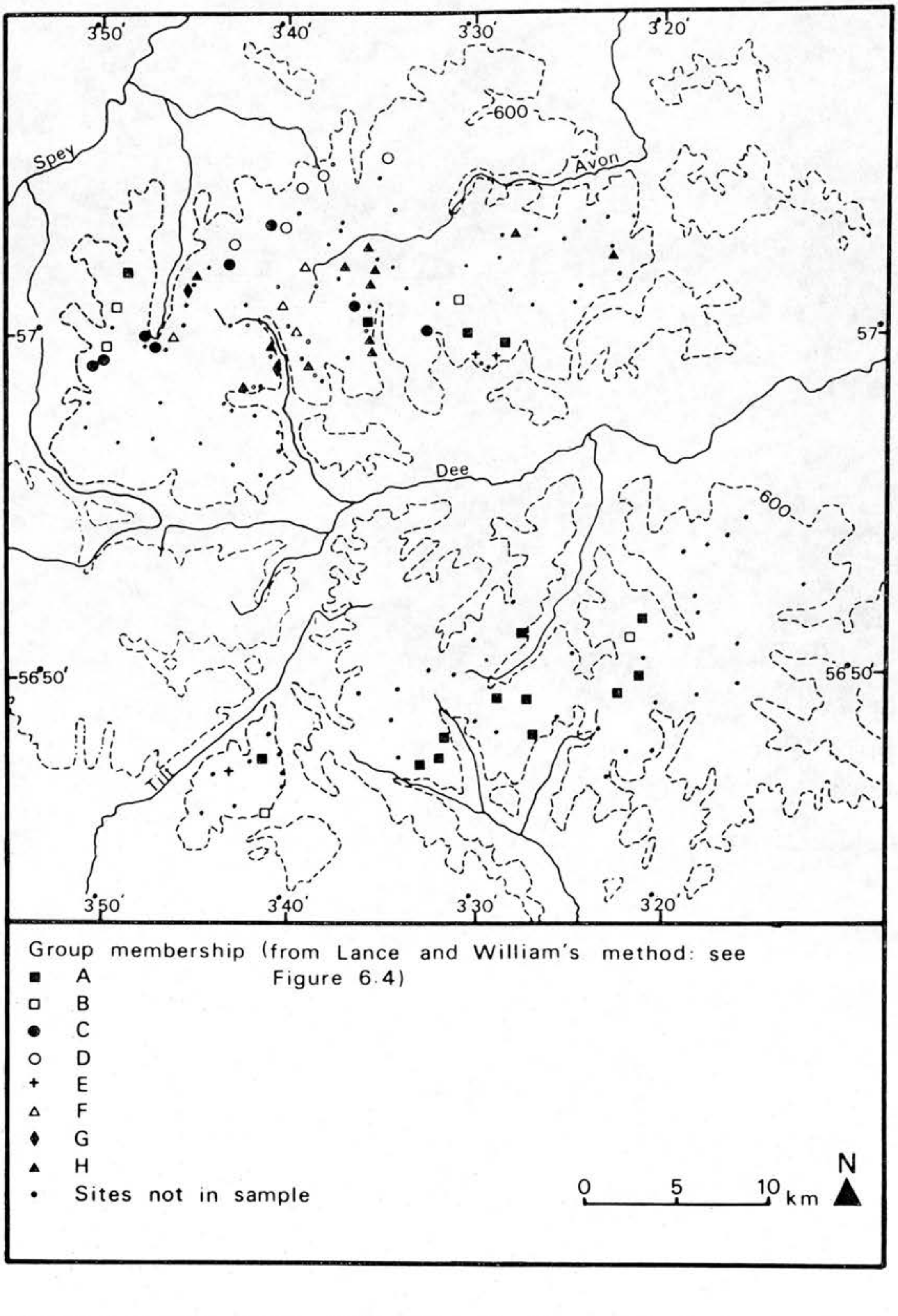


Figure 6.7: The group membership of sites and their location within the study area.

method was used for further analysis for three reasons: (1) the output was clear; (2) the groups were similar to those listed in Table 6.6, and (3) it combined a number of sites from the Cairngorms with those from the SE Grampians. Eight groups were identified on the dendrogram in Figure 6.4 at a Euclidean distance coefficient of 2.60. This choice was subjective: a higher "cut-off" point would have produced a large group of 20 sites (A and B), while a lower one would have increased greatly the number of groups.

As cluster analysis uses the scores on the principal components as input, the groups should be visible on a plot of the scores on the first two principal components. Figure 6.8 shows this plot with group membership rather than the number of each site (see Figure 6.1). Groups F,G and H occupy quite distinct areas on the plot with extreme scores on the components. Groups G and H had very low scores on the first component (see Table 6.3) which differentiated between shallow and more incised basins. The sites in group F all have high values for top altitude, a variable which had a high loading on the second component. The remaining five groups are indistinct when plotted against the first two components, as only 40.3% of the variation is accounted for by the first two components.

The mean and range of values in each group are listed in Table 6.7 and show that on many variables there is considerable overlap between the values present in each group. A univariate F-ratio (statistic option 6 on the SPSS Discriminant program; Nie et al., 1975) was used to test the null hypothesis that the group means are equal on any of the variables. The null hypothesis was

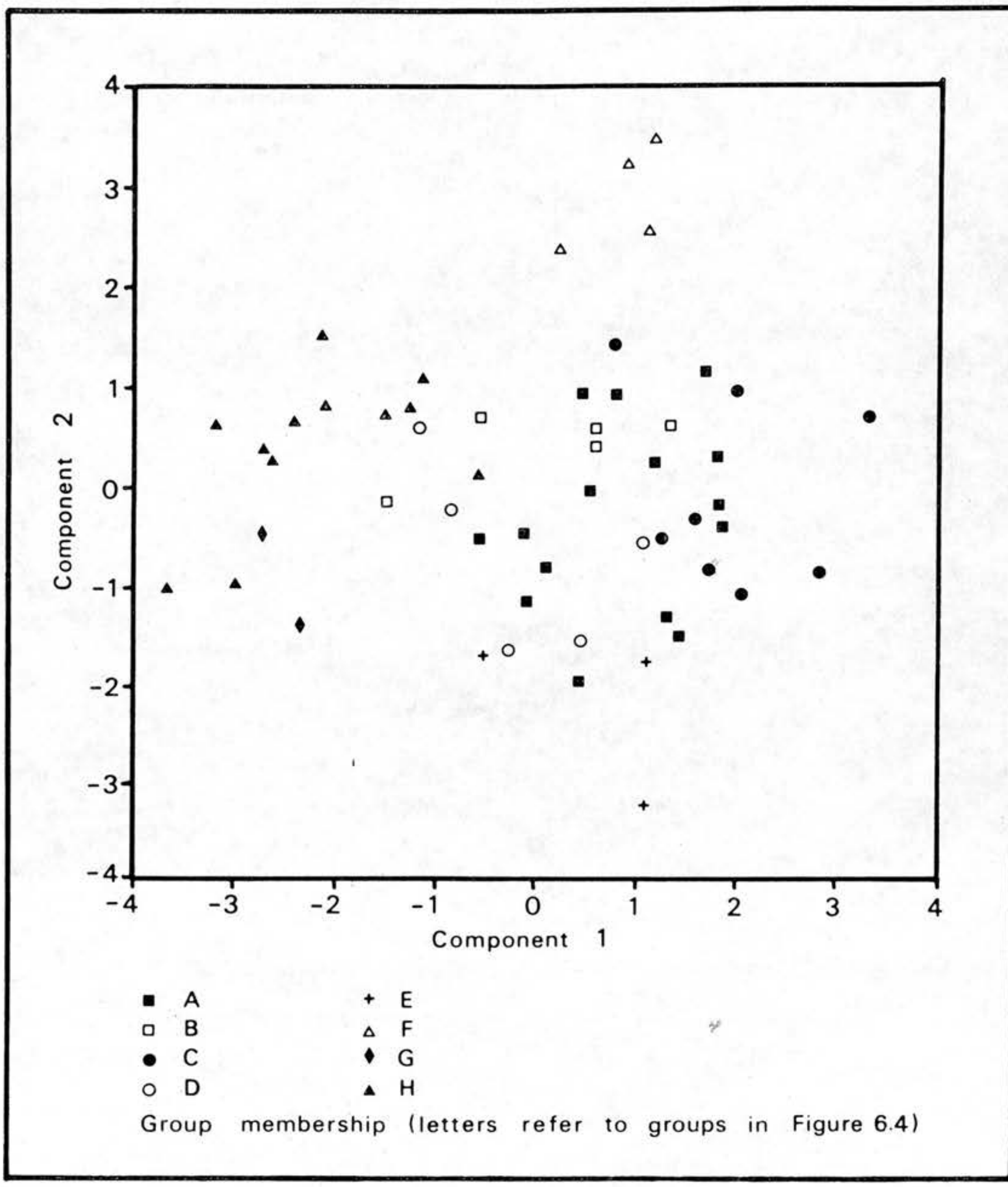


Figure 6.8: Group membership of sites plotted against their scores on the first two principal components.

rejected at the p = 0.02 level for global radiation, at the p = 0.01 level for leeward slope and at the p = 0.001 level for all other variables. These results suggest that the group centroids are quite different from each other, even though individual values may overlap. In only two instances do the range of values

Table 6.7: Characteristics of groups identified by the Lance and Williams's method. Groups as in Figure 6.4.

	A		B		C		D		All sites	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1	408.2	345.1 474.3	427.5	376.7 471.3	361.6	306.3 401.6	356.8	334.0 374.1	387.4	293.1 515.2
2	0.127	0.090 0.192	0.080	0.016 0.145	0.142	0.067 0.218	0.079	0.033 0.124	0.114	0.016 0.300
3	14.8	10.6 22.9	16.2	14.2 18.6	16.4	9.3 24.7	14.4	6.8 18.8	14.8	5.9 27.2
4	0.38	0.14 0.61	0.40	0.26 0.56	0.44	0.32 0.58	0.24	0.18 0.30	0.33	0.09 0.61
5	2062	300 3850	2630	1100 4350	3106	1900 5850	1467	900 2550	1946	0 5850
6	904	801 1075	979	887 1082	932	841 1003	994	918 1097	966	801 1268
7	993	944 1051	1002	961 1060	857	777 1040	744 *	599 841	967	599 1315
8	2913	2212 3444	2271	1700 2731	2342	1694 2862	2302	2100 2675	2721	1369 3737
9	57.4	35.9 70.3	42.5	38.7 48.8	62.8 *	51.2 75.2	55.5	41.1 62.6	51.8	26.1 75.2
10	48.9	27.9 81.8	37.6	23.6 52.3	64.6	44.3 81.9	41.6	23.8 53.8	44.8	5.4 85.2
11	69	30 91	103	68 150	101	67 137	108	66 147	107	30 180

Table 6.7 continued.

	E		F		G		H		All sites	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1	420.7	311.2 487.6	402.5	367.1 461.4	316.7 *	306.3 327.1	373.3	293.1 515.2	387.4	293.1 515.2
2	0.223 *	0.156 0.300	0.125	0.083 0.160	0.085	0.057 0.113	0.080	0.044 0.124	0.114	0.016 0.300
3	23.3 *	21.3 27.2	14.4	11.5 17.1	23.4 *	22.4 24.3	9.6	5.9 12.6	14.8	5.9 27.2
4	0.35	0.22 0.51	0.44	0.29 0.53	0.15 *	0.09 0.21	0.22	0.11 0.41	0.33	0.09 0.61
5	1050	350 1925	3156	2325 3975	0 *	0 0	1085	0 2650	1946	0 5850
6	893	867 919	1213 *	1145 1268	1021	992 1050	978	805 1073	966	801 1268
7	870	819 944	1176 *	1046 1315	1112 *	1094 1315	1018	960 1129	967	599 1315
8	3289 *	3081 3612	2556	1369 3087	2947	2506 3387	2971	2481 3737	2721	1369 3737
9	39.3 *	26.1 48.8	49.6	37.7 61.8	42.3	38.7 45.8	45.3	28.7 61.4	51.8	26.1 75.2
10	30.5	5.4 51.8	68.4	37.6 85.2	16.5 *	14.7 18.2	31.3	5.4 62.3	44.8	5.4 85.2
11	78	30 138	107	81 122	150 *	138 162	160 *	121 180	107	30 180

1 Global radiation
2 Basin ratio
3 Gully side slope
4 Form ratio
5 Fetch
6 Top altitude
7 Topographic rise
8 Leeward slope
9 Snowdrift
10 Wind-drift
11 Topographic exposure

present in a group not overlap with values in other groups: first, top altitude in group F, and second, topographic rise in group D. For the most part, however, differences between the groups only appear when the group means are examined.

Interpretation can be aided by looking at those groups with means of more than one standard devation from the mean for all 54 sites, these are marked "*" in Table 6.7. Of the 16 means marked in this way, 14 are for groups with less than five members. Although group G, for example, has only two members (9 and 25), seven of the means for that group are more than one standard deviation from the mean for all 54 sites. These two sites have shallow basins and are situated on exposed slopes, but do have very high values of gully side slope which distinguishes them from the sites in group H.

Low values of top altitude is the basic characteristic of sites in group A, with a mean value of only 904m (the mean of all sites is 966m). These sites tend also to have incised basins, with a mean value of 67^0 of topographic exposure and a range from 30^0 to 91^0(i.e., all members have below average exposure). Although the range of values of snowdrift and wind-drift are great, the mean values are higher than that for all 54 sites. Although sites in group A should entrap large amounts of snow (owing to their incised basins), the consistency of snowcover will be limited by the adverse influence of low values of top altitude on the supply and retention of snow.

Sites in group B tend to have quite high values of global radiation and below average values of snowdrift and wind-drift. The sites are quite unique in having very shallow (low basin ratio) but wide basins (high form ratio). Although the gullies should entrap large quantities of snow, the poor values of global radiation, snowdrift and wind-drift should lead to the snowcover being inconsistent.

The main features of sites in group C are wide basins and above average values of snowdrift and wind-drift, and should, therefore, have more consistent snowcover than most other sites. Sites in group D have very low values of basin ratio, the mean value being less than that for groups G and H which were assumed to be good examples of shallow, exposed basins (see section 6.2.2). The most distinctive feature, however, is the very low mean value of topographic rise which suggests that these sites will receive little orographic precipitation being on the very edge of the Cairngorms.

The main characteristics of sites in group E are very deep basins and gullies, and well below average supply of snow. The group means for basin ratio, gully side slope, snowdrift and leeward slope are all more than one standard deviation from the mean for all sites. Although the gullies have steep side slopes, the basin is the dominant feature as the gully is a continuation of the slopes of the basin (see sections 5.2.3 and 5.2.4). The low values of top altitude, snowdrift and wind-drift should mean that these sites receive relatively little snow and do not retain snow well.

Sites in group F are characterised by very high values of top altitude and topographic rise. The sources of these streams are located on the summit plateaux of the Cairngorms, and are the maximum values possible within the study area. This advantage should result in greater amounts of precipitation and lower temperatures at these sites and, therefore, more consistent snowcover.

The mean values of global radiation, gully side slope, form ratio, fetch, topographic rise, wind-drift and topographic exposure of the sites in group G are all more than one standard deviation from the means for all sites. Having only two members, this group is weak, the only difference between the sites and those in group H are the steep gully side slopes which should entrap considerable amounts of snow within the gully. This snow should be retained for long periods owing to the low values of global radiation and average top altitude.

Shallow and exposed basins with shallow gullies are the main features of sites in group H. Snowdrift and wind-drift are also below average, but global radiation and top altitude show great variation between the sites. These sites should have very limited snowfields and the least consistent snowcover of any group because of their relative inability to entrap snow and the low values of snowdrift and wind-drift.

No group should clearly have the most consistent snowcover because each has at least one disadvantage, although group F appears most favourable and group H least. On most of the variables there is considerable overlap between the groups. Discriminant analysis can be used to test the null hypothesis that the group means are equal, and so test the efficiency of the classification.

6.4 DISCRIMINANT ANALYSIS

6.4.1 Background

Using principal components analysis and cluster analysis, groups of sites with similar characteristics were identified in the last section. Although there was considerable overlap between the groups, the group centroids appeared to be reasonably distinct from one another. The statistical significance of the groups can be tested using discriminant analysis.

Discriminant analysis can be used to find the linear combination of variables which produces the best possible discrimination between the groups derived from a cluster analysis (Davis, 1973). The linear combination is of the form:

$$Di = di(1)Z(1) + di(2)Z(2) + \ldots\ldots + di(k)Z(k)$$

where Di is the score on discriminant function i, di(k) are the weighting coefficients and Z(k) are the standardised variables. The maximum number of coefficients is either one less than the number of groups or equal to the number of variables, whichever is less. The functions are derived in order of decreasing power of discrimination and are analogous to principal components (see section 6.2.1). As with principal components, the discriminant functions are independent of each other.

There are two methods by which the discriminant variables can be selected. The first method uses all of the original variables, regardless of the power of each to discriminate between the groups. The second method selects variables on the basis of their discriminating power. The selection of the variables in the second method is acheived using one of five criterion:

1. maximise the F-ratio between the groups (the F-ratio is a

measure of the estimate of the between-group variance divided by the within-group variance) (Johnston, 1980);

2. maximise the smallest F-ratio between any pair of groups;

3. maximise the Mahalonobis distance between the two closest groups (a measure of the distance between group centroids in multidimensional space);

4. minimise the residual variation after each step; and

5. maximise the increase in Rao's V after each step.

A variable will only be selected if its partial multivariate F-ratio is larger than a specified value (as in stepwise regression analysis), in this case the value is 6.50. All five criterion are available on the SPSS package (Nie et al., 1975). Use was made of (1), (3) and (5) to compare and contrast results.

Although discriminant analysis requires that the data be normally distributed and that the group variance-covariance matrices be approximately equal (Marriott, 1975), it appears sufficiently robust to accommodate moderate skewness or kurtosis (Marriott, 1975; Mather, 1976; Webster, 1977). The null hypothesis that the sample group variance-covariance matrices are equal can be tested using Box's M test (Mather, 1976), which is available on the SPSS Discriminant program (Nie et al., 1975). If the null hypothesis is rejected, it can be assumed that the variance and covariances are heterogeneous and that the distributions are not normal. Box's M test assumes multivariate normality, however, and tests for normality are not well developed (Mather, 1976). Hope (1968, p.29) suggests that discriminant analysis is neither too sensitive to departures from non-normality nor is it greatly affected by moderate heterogeneity of variances and covariances. Mather (1976, p.435) concluded that discriminant analysis could be still used if the null hypothesis was rejected.

Although discriminant analysis produces classification functions that can be used both to test the efficiency of the discrimination (by calculating the likely group membership of the sites used in the analysis) and to allocate new sites to their appropriate groups, the functions are biased towards the sites used in the analysis. Removal of a certain proportion of sites (at random from the matrix) would allow the accuracy of the analysis to be assessed. The discriminant functions, for example, could be derived from 44 sites and validated using the ten remaining sites.

If discrimination is possible, and a certain set of related variables can discriminate between the groups successfully, then classification functions can be calculated from these variables and used to allocate new sites to their appropriate groups. All sites within the study area could then be classified without having to rerun the cluster analysis.

6.4.2 Analysis of results

The null hypothesis that the group variance-covariance matrices are equal had to be rejected. Box's M was 89.0 with a corresponding value of F of 2.139, so with 30 and 989 degrees of freedom, this value is significant at the p = 0.001 level. Possible causes of this heterogeneity may be the small membership of groups D,E,F and G, non-normality of the data and differences between the sites and groups. Noting the advice of Mather (1976), it was decided to proceed with the analysis but with due caution owing to the result of the Box's M test.

The standardised discriminant function coefficients (derived using the criterion of maximising the increase in Rao's V) are listed in Table 6.8. The first three functions account for 97.8% of the variance. The null hypothesis that the discriminating power of the functions is zero in the population was rejected for the first three functions at the $p = 0.001$ level. Addition of the fourth function reduces the value of p to 0.064, so only the first three functions are retained.

Table 6.8: Standardised discriminant function coefficients.

	1	2	3	4
Top altitude	-0.07	0.72	0.64	-0.48
Topographic rise	1.10	0.08	-0.30	0.10
Wind-drift	0.65	-0.39	0.55	0.65
Topographic exposure	-0.48	0.88	-0.04	0.48
Eigenvalue	4.36	3.39	0.92	0.25
% variation	48.9	38.0	10.3	2.8

Of the eleven possible discriminant variables, only four were entered into the analysis (F-to-enter = 6.50): topographic rise, topographic exposure, wind-drift and top altitude, i.e., these discriminate best between the centroids of the groups identified by cluster analysis. Table 6.7 showed that three of the eight group means on topographic rise were more than one standard deviation from the mean for all 54 sites, suggesting that a number of the groups may be distinguished by their values on topographic rise. The importance of topographic rise in the multivariate analysis is also shown in its strong influence on the second and fifth principal components (see Table 6.1). Topographic rise discriminates between groups of sites that are situated on the edge of the Cairngorms and, therefore, have low values and those more in the centre of the Cairngorms and SE Grampians, where the values are much higher. This variable may identify sites or groups of sites, therefore, with varying amounts of orographic precipitation.

Topographic exposure discriminates between sites with shallow basins and those with more incised basins. The relatively high correlations between topographic exposure and other variables (see section 5.4) implies that it "represents" other variables that measure basin and gully morphology. The importance of topographic exposure in the outcome of the principal components analysisand cluster analysis was noted in section 6.2.

Sites with high topographic exposure tend to lie on exposed slopes and, therefore, have limited fetch, which may explain the inclusion of wind-drift as a discriminant variable. Wind-drift also shows remarkable variability between sites and to a lesser extent between the groups in Table 6.5. The scale of this variability was examined in sections 4.6.2 and 5.2.11, where it was suggested that wind-drift may be more variable spatially than snowdrift.

The fourth discriminant variable is top altitude, the influence of which on the classification of sites was examined in sections 5.3 and 6.3.2. As top altitude has a high loading on the second component, it strongly influences the classification of sites (see section 6.3.2). In part, this is because of the difference in values between sites in the SE Grampians and the Cairngorms (see section 5.3) and the tendency for sites in the former area to be grouped together (see section 6.3.2).

Topographic rise and wind-drift represent two aspects of the supply of snow. Top altitude influences both the supply and retention of snow, while topographic exposure influences the entrapment of snow. The discriminant functions, therefore, represent the supply, and to a lesser extent the entrapment and retention of snow.

The three functions identified by discriminant analysis are:

$$1 = -0.453X_1 + 1.205X_2 + 0.728X_3 - 0.926X_4$$
$$2 = 0.734X_1 + 0.325X_2 - 0.136X_3 + 0.582X_4$$
$$3 = 0.532X_1 - 0.284X_2 + 0.652X_3 - 0.097X_4$$

where X_1 is top altitude, X_2 is topographic rise, X_3 is wind-drift and X_4 is topographic exposure. Topographic rise has the highest loading on (1), top altitude and topographic exposure on (2) and wind-drift on (3). Each site has a score on each discriminant function, which can be plotted as shown in Figure 6.9. The first function discriminates between groups A,C,D and F. Sites in group D, for example, have very low scores and are located on the northern edge of the Cairngorms (see section 6.3) where there is little topographic rise to the north and west. The second function discriminates between groups A,B,D,G and H. These groups represent the extremes of topographic exposure, with group B being incised and G and H being shallow.

The functions classified 46 (85%) of the sites correctly. Sites classified incorrectly include the two in group G. It was noted in section 6.3.2, that the only difference between sites in group G and those in H was the steep gully side slopes of sites 9

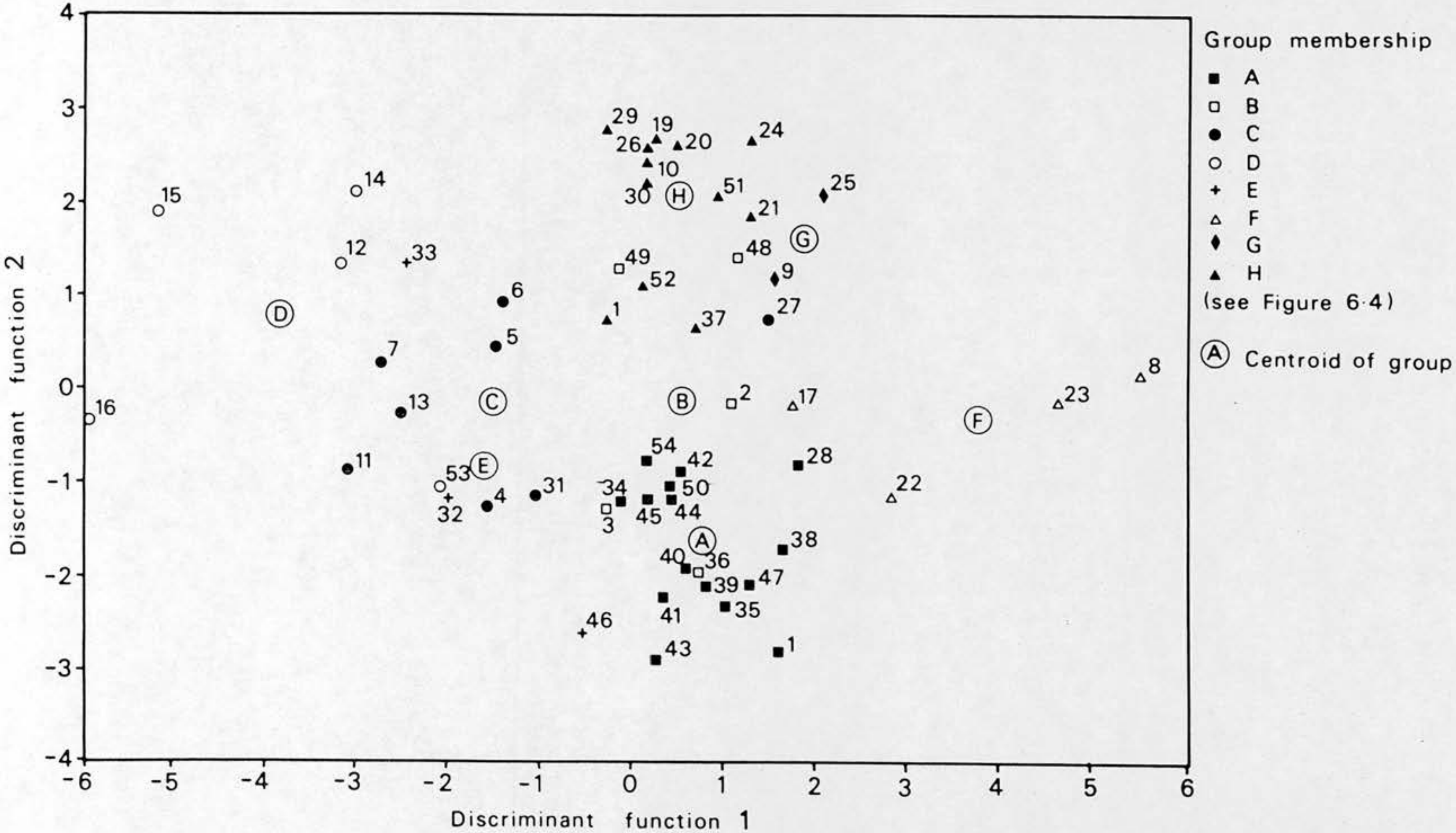


Figure 6.9: Plot of the scores on the first two discriminant functions.

and 25. As gully side slope is not a discriminant variable, sites 9 and 25 are classified along with the sites in group H.

Ten sites were removed at random from the total of 54 sites, and functions derived from the residual of 44 sites. Topographic rise, topographic exposure, top altitude and wind-drift were identified as the discriminant variables, although the F-to-enter was set at 4.80 rather than the value of 6.50 for the original. Box's M was 74.9, which when converted to an F-ratio of 1.724 (with 30 and 1014 degrees of freedom), was significant at the p = 0.01 level, which is very similar to the results for the original analysis. Table 6.9 shows the actual group membership of the ten sites and their predicted membership in the original and test analyses.

The results from the test analysis are identical to those for the original analysis using the 54 sites. The same three sites were misclassified, giving a correct classification rate of 70%. The functions, therefore, appear to be accurate and the original

Table 6.9: Calibration of the efficiency of the classification functions. A = actual membership; B = predicted membership from 54 site matrix; C = predicted membership from 44 site matrix. * = misclassified sites.

site	A	B	C
6	3	3	3
17	6	6	6
19	8	8	8
25	7	8 *	8 *
29	8	8	8
33	5	3 *	3 *
41	1	1	1
45	1	1	1
49	2	8 *	8 *
54	1	1	1

classification to be stable. The eight classification functions, which can be used to allocate new sites to their appropriate group (see Chapter 9), are listed in Table 6.10.

Table 6.10: Classification functions derived from the 44 site test sample.

1	$0.140X_1 + 0.274X_2 + 0.447X_3 - 0.016X_4 - 213.10$
2	$0.162X_1 + 0.260X_2 + 0.344X_3 + 0.052X_4 - 222.43$
3	$0.151X_1 + 0.225X_2 + 0.427X_3 + 0.079X_4 - 184.95$
4	$0.176X_1 + 0.175X_2 + 0.258X_3 + 0.162X_4 - 168.94$
5	$0.144X_1 + 0.235X_2 + 0.266X_3 + 0.004X_4 - 176.21$
6	$0.199X_1 + 0.323X_2 + 0.515X_3 + 0.051X_4 - 341.03$
7	$0.174X_1 + 0.263X_2 + 0.261X_3 + 0.120X_4 - 244.10$
8	$0.174X_1 + 0.243X_2 + 0.299X_3 + 0.164X_4 - 227.40$

X_1 Top altitude X_3 Wind-drift
X_2 Topographic rise X_4 Topographic exposure

6.4.3 Discriminant analysis of sites grouped by location

It was suggested in section 6.3.2 that sites in close geographical proximity might have similar supply, entrapment and retention characteristics. Evidence to support this hypothesis included the clustering of some neighbouring sites in the classifications shown in Figures 6.3 to 6.6. This hypothesis can be tested by classifying the sites according to mountain groups and using discriminant analysis. Nine groups were identified: Glen Feshie hills, Braeriach/Cairn Toul, Cairngorm, Ben Macdui, Beinn Mheadhoin/Derry Cairngorm, Beinn a' Bhuird/Ben Avon, East Glenshee, West Glenshee and Beinn a' Ghlo. The null hypothesis being tested is that no differences exist between the groups.

The group variance-covariance matrices were not equal. Box's M test was 106.6, which when converted to an F-ratio of 1.816 (42 and 1475 degrees of freedom), is significant at the $p = 0.0012$

level. A possible cause of this is the small number of sites in some of the groups. The null hypothesis that the group means are equal on a variable was rejected at the p = 0.05 level for global radiation, form ratio, fetch and wind-drift, at the p = 0.01 level for gully side slope and top altitude, and at the p = 0.001 level for topographic rise, leeward slope and topographic exposure. The null hypothesis could not be rejected for basin ratio or snowdrift.

Three functions were derived, of which the first two accounted for 95% of the variance. The null hypothesis that no discriminating power exists within the population can rejected at the p = 0.001 level for the first two functions but not for the third. Topographic rise, top altitude and topographic exposure were the discriminant variables. The functions, however, were only able to classify 28 of the 54 sites (52.0%) correctly. These results suggest that classification of sites according to their mountain location is feasible, but that it is far from being an optimal classification.

6.6 CONCLUSIONS

1. The eigenvalues and loadings of the principal components are relatively low because the relationships between the variables were not causal.

2. The method identified two basic types of site: (1) those with relatively deep and incised basins, and (2) those with shallow basins on exposed slopes with limited fetch. Several other patterns were identified, most notably sites with high values of

top altitude tend to have long fetch and high values of topographic rise, and sites with high values of global radiation tend to have low values of snowdrift.

3. Variables prominent in all three analyses were topographic exposure, topographic rise, leeward slope, top altitude and fetch or wind-drift. These variables, with the exception of topographic exposure, represent the supply and retention of snow.

4. There are few sites with good scores on all five components, so it is difficult to determine which sites should have the most consistent snowcover. This problem is partly one of interpretation and one of paucity of data on the processes involved.

5. The scores on the components can be interpreted as valid measures of the natural potential of sites for downhill skiing.

6. The sites were grouped into eight classes which were quite distinct in their consistency of snowcover potential. The classes were significantly different from each other, although there was considerable overlap between individual sites.

7. The method produces three types of information: (1) principal component scores; (2) classification functions which can be used to allocate new sites to their appropriate groups; and (3) loadings of the original variables on the components.

The next chapter attempts to validate the results of this chapter using regression analysis and measurements of the extent of snowcover. The information produced by the method is analysed further in Chapter 8 and applied in two small case studies in Chapter 9. The results are critically examined in Chapter 8.

CHAPTER 7: VALIDATION OF VARIABLES AND PRINCIPAL COMPONENTS

7.1 INTRODUCTION

The analysis of the morphology of sites in Chapters 5 and 6 was based largely on existing knowledge and on several assumptions about the influence of the relationships between variables on the consistency of snowcover at sites. No reference was made to the actual consistency of snowcover, owing to the absence of data. It was argued in Chapter 2 that what data existed on the consistency of snowcover would be used to validate, verify and interpret the results from the measurement of the natural potential of sites. This chapter has two aims:

1. to assess the validity of the original variables and the scores on the principal components as measures of natural potential (i.e., step six in Table 2.6); and
2. to improve understanding of the processes that influence the consistency of snowcover.

Measurement of the amount and consistency of snowcover will be described and an attempt made to assess how representative each season used in the analysis is of trends during the 30 winters since 1954/5.

7.2 MEASUREMENT OF THE CONSISTENCY OF SNOWCOVER

The dependent variable identified in Chapter 3 to represent the consistency of snowcover was the extent or depth of snow at a particular site. The extent of snowcover was defined as the length of snow in a gully on a particular day expressed as a percentage of the total length of the gully. This is by definition a relative measure, as the value for one site is meaningless unless compared with values at other sites on the same day.

This definition assumes that the extent of snowcover can be equated with the depth of snow. If two sites, for example, had values of 50% on a particular day then they should have equally consistent snowcover. If the remaining snow at one site, however, was of greater depth than at the other and assuming that the rate of melt was constant between the two sites, the snow would last longer at that site and be more consistent. As the consistency of snowcover is related more accurately to the depth, rather than the extent, of snow, the influence of the morphology of sites may become visible only at a late stage in the period of melt, i.e., when only deep deposits of snow remain. The coefficients of determination might be higher, therefore, for those dates on which the period of melt is well advanced. As the period of melt progresses into the summer and autumn, the remaining deposits of snow are likely to occupy sites with increasingly better supply, entrapment and retention characteristics (see Chapter 9).

The definition of the dependent variable, however, was based upon the nature of the data available rather than on any theoretical considerations. Data on the extent of snowcover can be collected from aerial photographs, Landsat scenes and fieldwork. These are discussed in turn.

Four sets of aerial photographs (18.4.55, 1.4.65, 25.4.68 and 13.4.81) were identified in Chapter 2 to be of use in the measurement of the extent of snowcover. As shown in Table 2.10, the scale of each set is different, varying from 1:10,000

(18.4.55) to 1:54,000 (1.4.65). A Grants Projector was used to enlarge or reduce the photographs to a common scale of 1:25,000. The extent of snowcover at each site was then measured from the central part of each photograph to avoid distortion. The data are listed in Appendix 7.

Two Landsat scenes (20.4.76 (path 222, row 20) and 3.4.81 (path 222, row 20)) were identified in Chapter 2 to be of use. In both cases, the snowline had been mapped (see section 2.4.3). The extent of snowcover at each site was measured from these maps, but there were many with zero values. The aerial photographs taken on the 13.4.81, however, show that many of the sites with zero values on the 3.4.81 scene did in fact have snowcover. No snow had fallen between these dates (see Appendix 4). Funds were provided by the Natural Environment Research Council to enable the researcher to reinterpret the Landsat scenes using the GEMS image interpretation facility at ERSAC Ltd., Livingston.

On a "raw" scene, the range of reflectance values for the pixels are concentrated frequently within a short range. An Auto-Gaussian stretch was applied to each scene to stretch the values over the full range of possible values from 0 to 255. This improves the contrast in the light and dark ranges of the scene and so aids interpretation. A density slice was then applied to distinguish between areas of snowcover and the rest of the scene, with reference being made frequently to the aerial photographs taken on the 13.4.81. The range of each slice, and those chosen by the Macaulay Institute (MISR) for the original work, were:

	MISR	NEW
20.4.76	141 - 255	121 - 255
3.4.81	53 - 255	36 - 255

The results for the 20.4.76 scene were satisfactory, with considerably more snow measured in the gullies than from the original maps. The data were of approximately normal distribution. The results for the 3.4.81 scene did not improve, however, on the original data (the data still contained many zero values), so use was made of the aerial photographs taken on the 13.4.81. Output was in the form of colour transparencies (the cost of producing maps was too high), which were then viewed against OS maps at the scale of 1:25,000 and the extent of snowcover measured. The data are listed in Appendix 7.

To mitigate the argument that validation is based only on the extent of snowcover (which has several limitations), attempts were made to measure the depth of snow at sites in April 1984 and April 1985. An important consideration was that there should be little change in weather and snow conditions during the period of survey, as the data would be of little use if heavy falls of snow or rapid melt occurred. The sites had to be surveyed in a short period of time, therefore, so ease of access was very important. The sample, therefore, is not a random one, although the sites do cover a wide range of morphology (see Appendix 7). The sites surveyed were 3,4,5,13,14,14!,38,40,45 and 49 (site 14! is Allt Coire an t-Sneachda and, although not in the 54 site matrix, this site was easily accessible and so included to increase the size of the sample).

In 1984, the survey was undertaken between the 12th and 24th of April and between the 10th and 16th of April in 1985. The depth of snow was measured using a three metre aluminium probe or, for deep drifts, one metre sections from a peat bore that could be joined together. The depth of snow was measured at six points on each transect, as shown in Figure 7.1. These transects were 100m apart and matched the location of the transects at which the side slope of each gully was measured (see sections 3.3

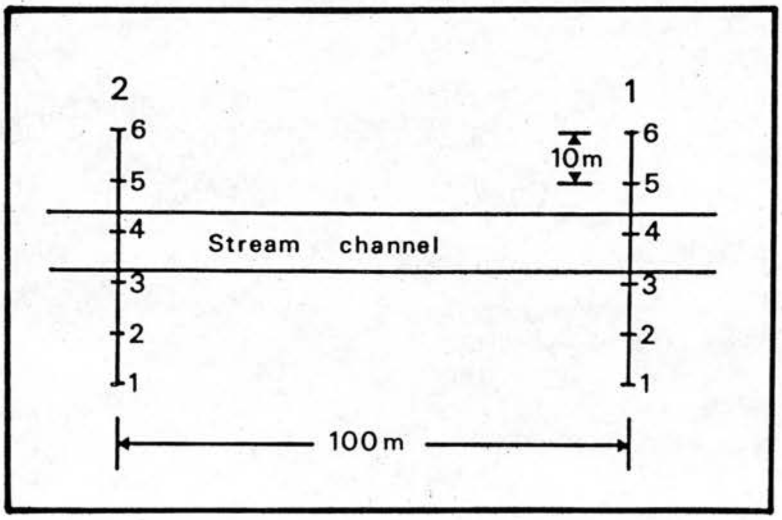


Figure 7.1: The measurement of the depth of snow in a gully.

and 5.2.4). For the ten gullies there were 168 transects (1008 points) at which the depth of snow was measured. Several measurements were taken at each point and the mean value used. Five sources of error were noted in the measurement of the depth of snow:

1. when the ground surface was soft, the probe often sank in to give a false depth;

2. snow was often lying over the vegetation leaving pockets of air within the vegetation (particularly evident in heather);

3. layers of ice within the snow could be mistaken for hard

ground;

4. stones on the bed of a stream, which were often large and could give results which were misleading; and

5. "snow bridges" over the stream channel which affected the actual depth of snow.

Figure 7.2 shows the influence of snow bridges on the depth of snow, where "A" is the measured depth and "B" is the actual depth of snow. What is being measured, therefore, is the distance from the surface of the snow to the ground surface.

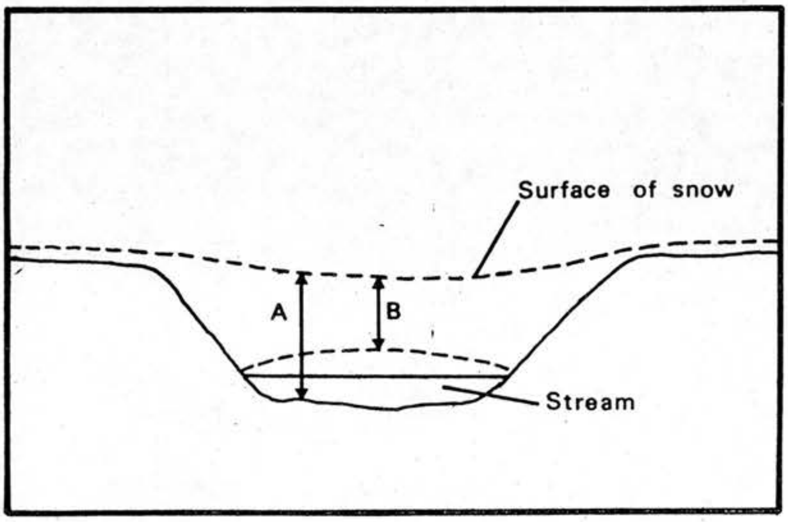


Figure 7.2: The influence of snow bridges on the measurement of the depth of snow.

Table 7.1 shows the weather conditions during the period of each survey. The maximum air temperature (A) and amount of precipitation (C) are the means of values recorded at Braemar and Lagganlia by the Meteorological Office. A temperature lapse rate of 8^0C per 1000m was applied to predict the temperature at an

Table 7.1: Weather conditions at Braemar and Lagganlia during the period of survey.

	APRIL 1984				APRIL 1985			
Date	A	B	C	D	A	B	C	D
10	---	---	---	---	6.7	4.3	2.0	1.7
11	---	---	---	---	7.5	5.1	0.9	0.7
12	7.7	5.3	0.8	3.0	8.4	6.0	1.1	5.9
13	10.6	8.2	tr	9.3	9.0	6.6	3.2	4.4
14	10.2	7.8	0.6	7.3	9.2	6.8	0.2	7.4
15	6.0	3.6	1.4	8.1	11.0	8.6	2.0	0.4
16	7.3	4.9	0.7	8.1	14.5	12.1	0.1	2.1
17	9.4	7.0	1.0	7.7	----	----	---	---
18	10.4	8.0	0.1	0.0	----	----	---	---
19	12.5	10.1	tr	1.3	----	----	---	---
20	13.0	10.6	tr	0.7	----	----	---	---
21	12.8	10.4	tr	6.3	----	----	---	---
22	15.9	13.5	tr	12.9	----	----	---	---
23	21.3	18.9	0.0	12.6	----	----	---	---
24	22.3	19.9	0.0	12.6	----	----	---	---
TOTAL			4.6	89.9			9.5	22.6

A Max. temperature (station level) C Precipitation (mm)
B Max. temperature (600m) D Sunshine (hours)

altitude of approximately 600m (B). The amount of sunshine (D) was recorded only at Braemar.

Snow fell above 750m on the 15th and 17th of April, 1984, but the amount was small. Considerable melt took place after the 19th, owing to high values of temperature and sunshine. A simple day degree correction of 3.0mm per day C was used (Morris, 1982, 1983; Ferguson, 1984) to allow for melt during the period of study, so that all data were comparable. Correction was made to the first day of the survey.

The period of survey was much shorter in April 1985, owing to the absence of snowcover below 750m. Temperatures were relatively low and the amount of precipitation quite high. Snow fell above 750m on the 10th, 11th and 12th, but the amount was small. Owing to the short period involved and fieldwork observations showing little melt, no corrections were made to the original data. The depth of snow at each transect in both periods are listed in Appendix 8.

7.3 WEATHER AND THE SUPPLY OF SNOW

Mean values of snowdrift and wind-drift over the 30 winters were used in Chapter 6. It is important, therefore, to determine how representative the winters to be used to validate the results are of the last 30 winters. Table 7.2 shows the directional source of snowdrift and wind-drift, and Table 7.3 shows the general weather conditions, for the winters under study. All weather data are listed in Appendices 2 to 6.

The main features of the winter of 1954/5 were higher than average precipitation and wind speed, giving a high value for snowdrift of 425. Snowdrift was particularly high for the months of December and February. There were conspicuous thaws in late December and January; aerial photographs taken on 4.2.55 (Table 2.1), show thin new snowcover above 600m (from snowfalls on 1.2.55 and 2.2.55) and old, deep drifts in the gullies, probably remnants of the storm on 12.1.55. Winds from the start of February were predominantly from the NW, and included two storms on 17.2.55 (D = 48) and 28.2.55 (D = 30). Some 54.8% of total snowdrift came from the NW quadrant, compared to the mean of 23.8% for the 30 winters. Wind-drift was dominated by winds from the SSE (32.2%) and WSW (42.7%). A thaw began on the 3.4.55 and lasted until the end of April. The thaw included five days of

Table 7.2: Snowdrift and wind-drift for the winters to be used to validate the results. Mean refers to that for the 30 winters.

	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW
Snowdrift								
1954/5	8.1	10.9	3.8	4.7	12.6	5.2	19.0	35.8
1964/5	5.2	5.5	4.2	5.2	9.1	33.9	23.5	13.4
1967/8	7.5	10.5	1.5	3.4	6.7	32.2	12.0	26.2
1975/6	2.7	0.0	13.5	13.5	15.0	25.8	19.6	10.0
1980/1	1.5	9.4	8.6	6.4	5.3	31.6	14.3	22.9
1983/4	0.9	8.9	26.6	22.1	6.2	19.8	11.0	4.5
1984/5	5.8	8.3	20.6	6.5	12.3	14.1	23.8	8.7
Mean	4.9	10.0	11.6	16.4	12.1	20.9	13.1	10.7
Wind-drift								
1954/5	0.0	1.9	1.6	32.2	12.8	42.7	5.5	3.2
1964/5	33.7	7.8	6.6	3.4	1.2	23.3	23.7	0.0
1967/8	0.0	0.0	6.4	6.8	6.5	17.4	36.8	25.9
1975/6	1.4	2.1	7.1	8.4	2.0	73.8	5.0	0.0
1980/1	5.3	5.0	45.4	5.8	6.9	4.7	24.7	2.0
1983/4	0.3	0.6	1.0	2.2	10.1	70.2	0.5	14.8
1984/5	4.5	15.6	13.9	6.7	39.2	15.6	0.0	4.7
Mean	3.3	5.4	9.3	19.6	17.4	18.2	16.2	10.4

Table 7.3: General weather conditions for the winters to be used to validate the results. Mean refers to that for the 30 winters.

	Mean wind speed	Mean ppt.	Mean max. temp.	Mean min. temp.	Snow drift	% ppt. snow
1954/4	14.8	388.8	4.9	-2.0	425	72.9
1964/5	13.1	312.5	5.5	-1.9	307	67.6
1967/8	12.9	320.6	5.8	-1.3	266	71.2
1975/6	13.6	256.3	7.4	-0.3	252	72.7
1980/1	15.7	279.2	6.8	-0.8	266	69.6
1983/4	17.0	513.6	5.9	-1.4	643	84.6
1984/5	16.3	301.6	5.4	-1.8	277	69.4
Mean	14.6	361.5	5.7	-1.4	355	70.6

rain and eight days of warm, sunny weather before the date on which the aerial photographs were taken.

The winter of 1964/5 had below average wind speed, precipitation, and % of precipitation falling as snow and snowdrift. Snowdrift came predominantly from the two western quadrants (79.9% compared with the mean of 56.8%). Some 80.7% of wind-drift came from the WSW, WNW and NNE, all much higher than the mean for the 30 winters. Snow fell on several days immediately before the 1.4.65, giving widespread cover above 600m. As this snow fell during winds with maximum speeds of 15.5m/s, there was limited drifting only. These snowfalls (all after the thaw of 13.3.65 to 17.3.65), were from the ENE and ESE. The influence of this on the pattern of snowcover depends upon how much of the preceding snowcover melted during the thaw, as snow before the thaw came largely from the west.

Mean wind speed, precipitation and snowdrift were well below average in 1967/8. Some 77.1% of total snowdrift came from the two western quadrants, as did 86.6% of total wind-drift. Most of the snowcover preceding the end of February melted during a thaw lasting two weeks in the first half of March. Two storms on the 17.3.68 (D = 21) and 19.3.68 (D = 15) came from the WSW. A week of rain followed at the end of March. The first week in April accounted for 15% of total snowdrift for the season and camefrom the NNW. The storm on 3.4.68 (D = 15) was accompanied by a mean wind speed of 22.5m/s. The aerial photographs taken on 25.4.68 were preceded by warm, wet weather from the 9th onwards.

The winter of 1975/6 had below average precipitation and snowdrift. Winds from the west were slightly less dominant than for 1964/5 and 1967/8, although 70.4% of total snowdrift still came from the SW and NW, and 73.8% of total wind-drift came from the WSW. The most distinctive feature of the winter was that no snowdrift was recorded during December. Most of April up to and after the date of the Landsat scene (20.4.76) had warm, sunny weather interspersed by several days with showers of snow. The snowcover observed on 20.4.76 was what remained from the heavy snowdrift in January, and in particular the storms of 2.1.76 (D = 24) and 19.1.76 (D = 21) which came from the SSW and WSW respectively.

The winter of 1980/1 had many days of snowdrift, but no storms (as defined in this study). The total snowdrift of 266 was well below average, as was precipitation. Snowdrift was dominated by winds from the SW and NW (74.1% of the total). Wind-drift came mainly from the ESE (45.4%) and WNW (24.7%). The occurrence of showers of snow, rather than of storms, probably provided only thin snowcover. A week of rain at the end of March followed by warm, sunny weather up to the 13.4.81 removed most of the snowcover. By that date there was little snowcover outwith the gullies and high plateaux of the Cairngorms.

The value of snowdrift in 1983/4 was 643, the highest value of the 30 winters. The winter was noted for exceptionally high precipitation of 513.6mm, a high mean wind speed of 17.0m/s and a total of 14 storms, that provided over 48% of total snowdrift. From the 1.1.84, there was little melt until the start of the period of survey (12.4.84). The storms on the 23.3.84 and 24.3.84 (total D = 74) came from the ESE and were accompanied by mean wind speeds of up to 28.5m/s (although speeds on the summit of Cairn Gorm may have reached 50m/s: Barton, pers. comm.). 48.7% of total snowdrift came from the SE, compared to the mean of 28% for the 30 winters. Wind-drift was dominated by winds from the WSW (70.2% of the total).

The amount of precipitation and snowdrift were well below average in 1984/5. Some 58.9% of total snowdrift came from the SW and NW, which is close to the 30-winter mean of 56.8%. Almost 55% of total wind-drift came from the SW, compared to a mean of 35.6% for the 30 winters. The most notable feature of the winter was the virtual absence of snowdrift during February. Four storms supplied 32.9% of total snowdrift with two coming from the ESE, one from the WSW and the other from the WNW. The period of survey was preceded by a week of rain (precipitation of 21.6mm).

It is clear that none of the seven winters are representative of the mean for the 30 winters, the nearest being 1984/5. The dominance of westerly winds will bias the results, as there is no opportunity to assess the influence of dominant easterly winds on the pattern of snowcover across the study area (data in 1984 being from fieldwork rather than photographic coverage).

7.4 RELATIONSHIPS BETWEEN THE VARIABLES AND THE EXTENT OF SNOWCOVER

This section examines the relationships between the original variables and the extent and depth of snowcover, with the aim of assessing their validity in representing the processes that control the consistency of snowcover. The correlation coefficients between the eleven independent variables and the dependent variable (the extent of snowcover or the depth of snow) are shown in Table 7.4. In Chapter 5, it was suggested that the Cairngorms and the SE Grampians could be treated as seperate

Table 7.4: Correlation coefficients between the variables usedin the analysis and the extent of snowcover (A - E) and depth of snow (F and G).

	A	B	C	D	E	F	G
Global radiation	-0.01	0.13	0.42	-0.12	-0.14	0.43	-0.47
Basin ratio	0.08	0.11	0.16	0.06	-0.35	0.18	-0.05
Gully side slope	0.50	0.15	0.13	-0.08	0.30	0.36	0.50
Form ratio	0.05	0.03	-0.61	-0.16	-0.29	0.73	0.50
Fetch	0.13	0.07	0.37	0.23	-0.19	0.23	0.48
Top altitude	0.18	0.32	0.74	0.61	0.38	-0.50	0.04
Topographic rise	0.16	0.18	-0.39	0.12	0.33	0.54	-0.15
Leeward slope	0.13	0.26	0.30	-0.01	0.39	0.48	-0.23
Snowdrift	0.05	0.32	-0.03	-0.16	-0.07	-0.24	0.06
Wind-drift	0.10	0.28	0.23	0.14	-0.19	0.58	0.90
Top. exposure	-0.20	0.15	0.17	0.22	0.22	-0.17	0.09
Sample size	30	51	21	50	31	10	9

A: 18.4.55; B: 1.4.65; C: 25.4.68; D: 20.4.76; E: 13.4.81
F: April, 1984. G: April, 1985.

Table 7.5: Correlations between the variables for the Cairngorm and the SE Grampian sites.

	Cairngorms			SE Grampians		
	B	C	D	B	C	D
Global radiation	0.12	0.53	-0.14	0.35	0.04	0.22
Basin ratio	-0.18	0.24	-0.35	-0.10	-0.14	-0.48
Gully side slope	-0.21	0.65	0.30	0.17	-0.08	0.10
Form ratio	-0.07	0.09	-0.29	0.07	-0.26	-0.33
Fetch	0.12	0.41	-0.19	-0.18	0.22	0.40
Top altitude	0.24	0.00	0.38	0.05	0.69	0.72
Topographic rise	0.23	-0.18	0.33	0.02	-0.20	0.44
Leeward slope	0.40	0.79	0.39	-0.19	-0.19	0.13
Snowdrift	0.24	0.58	-0.07	0.41	-0.54	-0.59
Wind-drift	0.25	0.76	-0.19	0.24	-0.33	0.12
Top. exposure	-0.09	0.41	0.22	-0.11	0.35	0.34

populations for top altitude and topographic rise. Where possible, seperate analyses were undertaken to determine if this did affect the results. Table 7.5 shows the correlations for data for sites in the Cairngorms and the SE Grampians on the 1.4.65, 25.4.68 and 20.4.76. The data for 18.4.55 and the 13.4.81 covered sites in the Cairngorms only.

With the exceptions of 25.4.68 and April 1984 and 1985, global radiation is poorly correlated with the extent of snowcover (Y). Two of the exceptions are positive correlations. The expected correlation was negative where Y would be higher at sites with low values of global radiation (see section 3.2), which may be partly due to sampling "error" as the number of sites is small and there were sharp differences in the extent of snowcover between the Cairngorms and the SE Grampians. Sites surveyed in the SE Grampians, for example, during April 1984 all have high values of global radiation, but as most snow came from the SE, greater amounts were deposited in that area than in the Cairngorms. Hence the apparent positive correlation between the two variables. The opposite situation existed on 25.4.68, i.e., sites on Beinn a' Bhuird had more snow and have a higher value of global radiation than the sites in the SE Grampians. This is confirmed by the relatively high positive correlation between the two variabes for the seven sites on Beinn a' Bhuird (Cairngorms) in Table 7.4. There are two possible explanations of the results:
1. theoretical global radiation on April 2 is a poor indicator of actual radiation during the season up to the date of observation;
2. global radiation is not important in accounting for variation in Y.

Given more time, a series of calculations could be made of global radiation to test the first point further. Global radiation could be computed, for example, for every day from after the last day of snowdrift to the date of observation. The results of Morris (1982, 1983) and Ferguson (1984) suggest, however, that global radiation is not important in explaining rates of snowmelt in the Scottish Highlands (see section 4.2.2). Similar results have been found for areas with predominantly cloudy weather during the melt season, e.g., New Zealand (Prowse, 1981; Moore and Owens, 1984).

Variables representing entrapment (basin ratio, gully side slope, form ratio and topographic exposure) are generally not well correlated with Y, with some exceptions, notably gully side slope on 18.4.55 and in April, 1984, form ratio on 25.4.68 and in April 1984 and basin ratio on 13.4.81. Gully side slope has a relatively high correlation with Y for the sites on Beinn a' Bhuird on the 25.4.68, but not amongst the sites in the SE Grampians on the same day. Topographic exposure has very low correlations with Y.

The definitions of some variables are deficient in several respects, most notably those for basin ratio and topographic exposure (see sections 5.2.3 and 5.2.12). These may cause relationships to be weak, but cannot be the only cause of the poor correlations, for some correlations are high. A further cause may be that as sites with high exposure tend to face east, they are located on the leeward slopes of mountains if the winds come from the west. Winds from the west were well above average in six of the seven winters (see section 7.3) which should have led to deep snowcover on east slopes, thus "masking" any differences caused by basin morphology. To a limited extent, therefore, snowdrift should be well correlated with Y, but this is not the case.

Indeed, in four cases, snowdrift is negatively correlated with Y. Strong negative correlations between snowdrift and Y were found for sites in the SE Grampians on the 25.4.68 and 20.4.76 (see Table 7.5). The definition of snowdrift has limitations (see sections 4.5 and 5.2.10), particularly with the assumption that snow is deposited on leeward slopes only. The existence of snow shadows and the use of a single wind direction in the calculation of snowdrift are further limitations that may result in snowdrift being over or underestimated at particular sites.

The correlations between Y and wind-drift and fetch are slightly higher than those for snowdrift. Snow that is redistributed by the wind is deposited only on leeward slopes and so there is a clearer relationship between it and the extent of snowcover. With the exception of the very high correlation of 0.90 in April 1985, the strength of the relationships are still quite low, however, a finding which raises doubts over the measurement of wind-drift. It was noted in section 5.2.11, that snow might drift into the gully along its length rather than only to the source of the stream from the fetch. If this occurs, then sites with shallow basins would receive large amounts of wind-drift along their length, owing to the absence of topographic obstacles (see Plates 4 and 5). This possibilty may mitigate the assumed negative influence of shallow basins on the entrapment of snow, which would explain further the low correlations between Y and variables representing the entrapment of snow.

Topographic rise and leeward slope are relatively well correlated with Y and, with several exceptions, the correlations are all positive. This would appear to support the hypothesis that topographic rise measures the amount of orographic precipitation and that long and gentle leeward slopes do not trap large quantities of snow. The correlations are, however, poor when compared with the results of Rhea and Grant (1975), who found a correlation of 0.90 between topographic rise and the amount of precipitation at weather stations. It must be noted, however, that in the study by Rhea and Grant:

1. the stations were up to 300km apart, and
2. topographic rise was measured in more detail for the NW quadrant only, because almost all winds came from this direction.

Top altitude is well correlated with Y, most notably for 25.4.68, 20.4.76 and April 1984. Whether the influence of top altitude on the extent of snowcover is due to an increase in the amount of precipitation or decreased rates of melt (owing to lower temperatures), or a combination of both, is not clear. Studies in other countries have similar or better results. Caine (1975) found a correlation of 0.66 between altitude and the accumulation of snow at 24 snowcourses in the Colorado Rockies. Yamada (1983) found one of 0.90 between the depth of snow and altitude at weather stations in the Japanese Alps. Similar results have been found by Spreen (1947), Storr and Ferguson (1972) and many others.

The mean top altitude of sites in the Cairngorms was found to be significantly different from that for sites in the SE Grampians (see section 5.3). As there is a sharp difference in the extent of snowcover between the two areas on 25.4.68 and 20.4.76, the high correlations between Y and top altitude may be caused by the difference between the two areas on that variable.

This can be tested by calculating the correlations between the two variables for sites in the Cairngorms and for those in the SE Grampians. If the influence of top altitude on Y is real, then all the correlations should be high. The results are:

	Cairngorms	SE Grampians	All sites
1.4.65	0.24	0.05	0.32
25.4.68	0.01	0.69	0.74
20.4.76	0.38	0.72	0.61

Although only seven sites from the Cairngorms were used for 25.4.68 (only Beinn a' Bhuird and Ben Avon were covered by the photographs), some relationship could have been expected. There was no correlation, and a high one for the 14 sites used from the SE Grampians. This finding suggests that top altitude was influencing the extent of snowcover only in the SE Grampians. The correlations between top altitude and Y on the 20.4.76 are high in both cases, which suggests that top altitude was influencing the extent of snowcover over the study area.

The dependent variable was plotted against the independent variables for each of the dates to determine if the data satisfied the requirements of multiple regression analysis (see next section). Figure 7.3 shows the distribution of values for the highest correlation on each date. These correlations are generally linear.

The relationship between gully side slope and the extent of snowcover on the 18.4.55, has a correlation coefficient of 0.50. The trend is approximately linear, although it is distorted by three extreme values, where the extent of snowcover was low. The correlation between snowdrift and Y for the 1.4.65 is only 0.32.

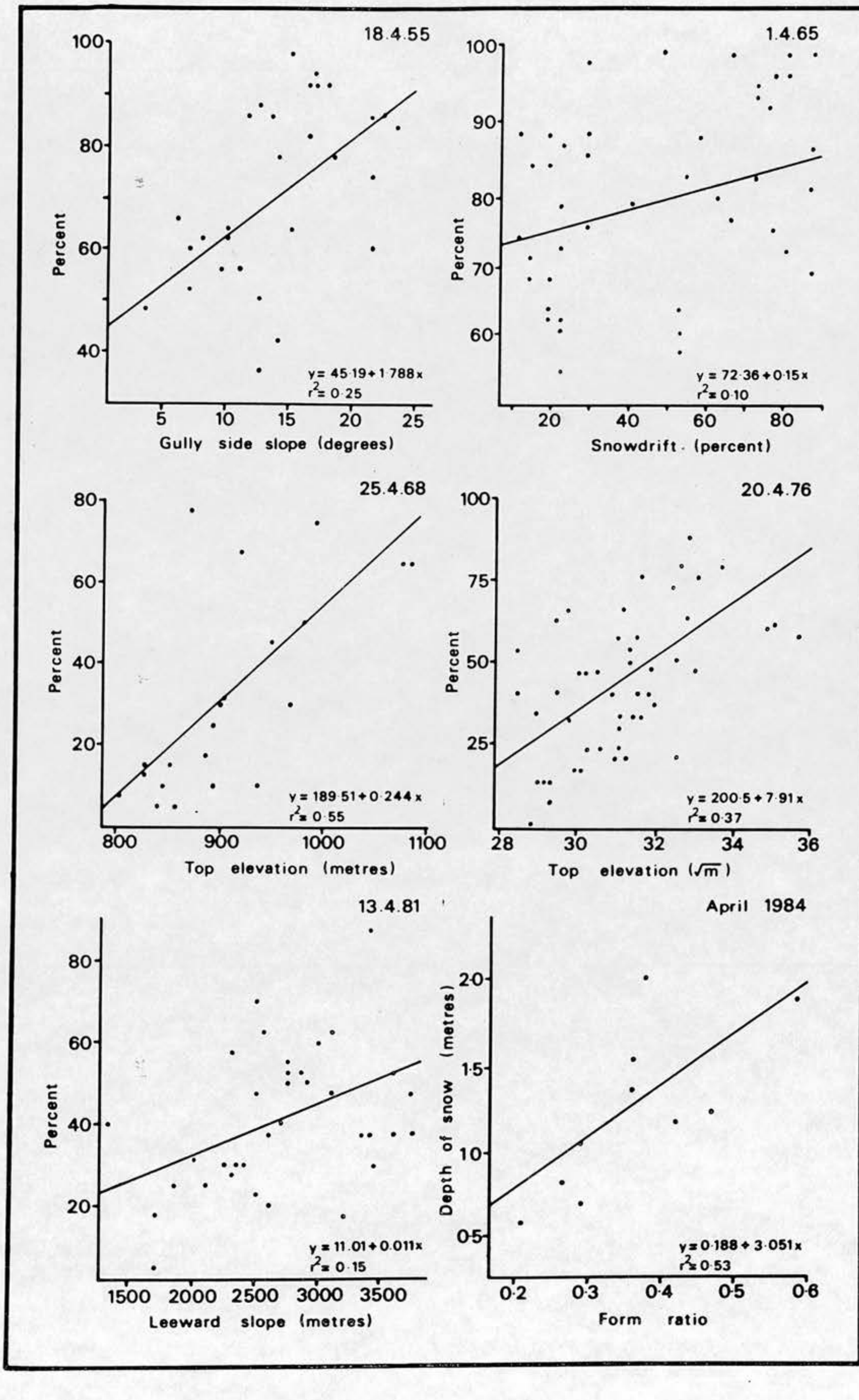


Figure 7.3: Plot of the six highest correlations against the dependent variable (Extent of snowcover or the depth of snow).

The gap between values of snowdrift (there is only one value between 30% and 50%), is probably due to the above average snowdrift from the west in that winter.

The relationship between top altitude and Y on the 25.4.68 is strong (r = 0.74) and linear. The relationship between top altitude and the extent of snowcover on the 20.4.76 is strong (r = 0.61) and linear, with a good spread of values around the regression line. The strongest relationship on the 13.4.81 is that between leeward slope and the extent of snowcover (r = 0.39), which is linear. The final plot shows the relationship between form ratio and the depth of snow measured in April, 1984. Although the correlation is high (0.73), it is based on ten values only, so is essentially weak.

The correlations between the original variables and the extent and depth of snowcover are generally low, although there are a number of exceptions. The variables with the highest correlations are gully side slope, form ratio, top altitude, topographic rise, leeward slope and wind-drift. Subject to the limitations of the dependent variable and the definition of some of the original variables, the results are quite satisfactory and the variables do represent the processes that control the consistency of snowcover.

7.5 MULTIPLE REGRESSION ON THE VARIABLES

The last section considered the individual influence of the variables on the consistency of snowcover. The aim of this section is to determine the extent to which they can account for variation in the extent of snowcover. The results can also be used to raise questions and hypotheses for future research.

Multiple regression analysis is based on seven assumptions:

1. the relationships between the variables should be linear;
2. the distribution of the data should be normal;
3. for every value of X, the mean of (Yi - Yi) must be zero (this assumption is usually met if the relationship is linear);
4. the data should not be dominated by a few large values;
5. the value of each observation on the independent variable(s) should be independent of all of the values of all others;
6. X and Y should be free of measurement error, and
7. the independent variables should be uncorrelated with each other (Johnston, 1980).

The plot of six of the relationships in Figure 7.3, showed that they were linear and were not seriously distorted by extreme values. It was concluded in Chapter 5 that the independent variables were largely uncorrelated with each other. The skewness and kurtosis of the distribution of each variable were calculated and the following transformations undertaken if the values were significantly different from zero at the $p = 0.05$ level:

1954/5, 1980/1	basin ratio (square root)
1964/5, 1975/6	basin ratio (square root), top altitude (square root)
1967/8	gully side slope (log), topographic exposure (log).

The multiple regression program "P2R" in the BMDP-77 package (Dixon and Brown, 1977) was used. A forward stepping procedure was adopted (the variables being entered in order of decreasing ability to account for variation in Y). The results of the MRA are listed in Table 7.6. The regression equations are listed in

Table 7.6: Results of the regression analyses.

Date	r^2	F	p	S.E.	Variables
18.4.55	0.44	3.06	0.10	15.7%	Gully side slope Top altitude Leeward slope Global radiation Basin ratio Snowdrift
1.4.65	0.46	5.02	0.01	10.2%	Snowdrift Top altitude Gully side slope Leeward slope Topographic exposure Wind-drift Basin ratio
25.4.68	0.85	51.43	0.001	11.3%	Top altitude Topographic rise
20.4.76	0.47	9.76	0.001	16.4%	Top altitude Topographic exposure Fetch Basin ratio
13.4.81	0.69	9.76	0.001	10.8%	Leeward slope Top altitude Gully side slope Wind-drift Topographic rise Basin ratio
April 84	0.70	4.76	0.05	0.32m	Form ratio Top altitude Leeward slope
April 85	0.84	16.15	0.01	0.10m	Wind-drift Gully side slope

S.E. Standard error of the estimate

Table 7.7.

As would be expected from the generally low correlations between the variables and the extent of snowcover examined in section 7.4, the coefficients of determination (R) are not particularly high. Those for 18.4.55, 1.4.65 and 20.4.76 are lowest, while those for 25.4.68 and 13.4.81 are high in view of

Table 7.7: Regression equations derived from results in Table 7.6.

18.4.55	$Y = -8.270 + 0.185X_9 + 48.731X_2 + 0.051X_6 + 0.009X_8 + 2.346X_3 - 0.141X_1$
1.4.65	$Y = -60.91 + 1.032X_3 + 37.587X_2 + 2.398X_6 + 0.005X_8 + 0.148X_9 + 0.116X_{10} + 0.121X_{11}$
25.4.68	$Y = 41.775 + 0.281X_6 - 0.272X_7$
20.4.76	$Y = -211.987 + 59.685X_2 + 0.004X_5 + 6.737X_6 + 0.197X_{11}$
13.4.81	$Y = -72.146 - 0.247X_{10} - 58.767X_2 + 0.061X_7 + 0.024X_6 + 0.010X_8 + 2.149X_3$
April 84	$Y = -5.891 + 5.559X_4 + 0.005X_6 + 0.0003X_8$
April 85	$Y = -0.7034 + 0.0084X_{10} + 0.0218X_3$

1 Global radiation
2 Basin ratio
3 Gully side slope
4 Form ratio
5 Fetch
6 Top altitude
7 Topographic rise
8 Leeward slope
9 Snowdrift
10 Wind-drift
11 Topographic exposure

the reservations about the definitions of the variables made in this chapter and in Chapter 5. The equations account for 70% and 84% of the variation in the depth of snow in April, 1984 and April, 1985 respectively but, being based on data for only ten sites, are not significant.

Several variables appear consistently in the regression equations: top altitude, leeward slope, basin ratio, and gully side slope. Apart from top altitude, these variables are different from those identified in the discriminant analysis (see section 6.4), although to a limited extent basin ratio measures the degree of incision of a basin and is quite well correlated with topographic exposure (one of the discriminant variables), and leeward slope measured the terrain upwind of a site, as did topographic rise (see section 6.5.2). The standard errors of the estimates are generally quite high, e.g., 15.7% for the 18.4.55 equation.

The coefficients of determination for 25.4.68, 13.4.82, April 1984 and April 1985 compare well with those of other studies, although it is difficult to compare results because different variables are used. All results compare favourably with those from the only other study of the extent or depth of snowcover in the United Kingdom to make use of regression analysis (Waring, 1981). Waring concluded that "..in only six out of the twenty four samples was the combination of elevation, aspect and slope variables significant (at the 0.05 level) in explaining the distribution of snow depth over the Maesnant (Wales) catchment" (p.94). Waring measured the depth of snow on thirteen days between November, 1977 and March, 1979 in a small sub-catchment of the Plynlimon basin in mid-Wales.

The US Army Corps of Engineers (1956) and Anderson and Pagenhart (1957) produced values of r^2 of 0.58 and 0.62 respectively. The dependent variable in both cases was the depth of snow measured at snowcourses in the coastal mountains of Oregon and California respectively. Independent variables were angle of slope, aspect, elevation, exposure, forest cover and solar radiation. The coastal mountains of California and Oregon experience often severe drifting of snow associated with storms in winter (Minnich, 1984), i.e., similar to the Scottish Highlands (see section 3.3), which may account for the similar results.

Most studies have used data collected in areas where the drifting of snow is not important. As the snow tends to fall evenly over the land, the influence of altitude and aspect is not modified. Examples of such studies include those by Spreen (1947), Hendrick et al. (1971), Meiman et al. (1971), Loijens (1972), Storr and Ferguson (1972), Michna and Paczos (1976) and Yamada (1982), and all have values of r^2 ranging from 0.71 to 0.93, and use depth of snow recorded at snowcourses which are usually located below the treeline where drifting is minimal.

Only recently have attempts been made to examine snowcover above the treeline. Unfortunately, these studies have all been site-specific with the aim of identifying and measuring the processes involved. The review of literature in Chapter 3 identified no regression analyses that had used data collected from above the treeline only, or had tried to relate snowcover to the morphology of gullies and basins.

Topographic rise and leeward slope were found to be important in the statistical analysis in Chapter 6 and the regression analyses in this chapter. The relatively low altitude of the study area and the number of barriers within it, may account for the relatively low coefficient of determination compared with that found by Rhea and Grant (1974) in Colorado. Their regular presence in this study, however, suggests that the work of Rhea and Grant (1974) and Rhea (1977) may be of relevance to studies of snowcover in the Eastern Highlands of Scotland. The results suggest that sites within a massif (such as the Cairngorms) have more consistent snowcover than those on the edge of the massif owing to an increase in orographic precipitation and turbulence as storms cross it.

Topographic rise and leeward slope can also represent the relative location of a site within a massif, e.g., a site with a high value of topographic rise will be located towards the centre of a massif rather than at its perimeter. As air reaches the massif it rises, cools and condenses to form clouds, which dissipitate on the downward slope, so the edge of the massif may be relatively free of cloud. This cloud system may be associated with precipitation, with little falling at the edge of the massif and rather more in the centre, where snowcover would be more consistent.

The relative importance of altitude, topographic rise and leeward slope suggests that the amount of precipitation may be important in accounting for variation in the consistency of snowcover. Sharp differences in the extent of snowcover were found on 25.4.68, 20.4.76 and April, 1984, which suggest that snow is depleted rapidly as storms cross the study area. The resultant pattern of snowcover, therefore, bears little relationship to the morphology of the land surface. The exact nature and influence of these snow shadows is not known because of the absence of data for most of the study area (see Chapter 8 for further discussion).

The value of r^2 is highest for 25.4.68 and 13.4.81, where the snowcover is confined to gullies, corries and high plateaux, where it is probably quite deep and, therefore, more consistent. The values of r^2 are lower for 18.4.55, 1.4.65 and 20.4.76 when snowcover was much more widespread. The influence of the morphology of sites may become visible, therefore, only at a late stage in the period of melt when only deep snow remains (as suggested in section 7.2). This possibility is confirmed by the coefficients of determination being high for the depth of snow measured in April of 1984 and 1985.

The difference (the residual) between the actual extent of snowcover and that predicted from the regression equations can be examined. Three sites have residuals of more than one standard deviation from the mean on three of the dates: Allt a' Choire Ghuirm (5), Allt a' Choire Ghuirm (12) and Allt Coire Buidhe (18). A further eight sites have residuals of more than one standard deviation from the mean on two of the dates: Allt a' Mharcaidh (1), Allt Meall Dubhaig (4), Beanaidh Bheag (11), Allt a' Choire Chais (15), Allt Coire an t-Sabhail (24), Allt Lochan Uaine (28), Allt a' Bhealaich Buidhe (50) and Buidheannach Burn (51).

Six of the eleven sites are situated on the northern edge of the Cairngorms (sites 1,4,5,11,12,15). Apart from Allt a' Choire Ghuirm (12), the regression equations under-predicted most of the values. This finding suggests that other processes are at work and/or the present variables do not represent the processes identified in Chapter 3 adequately. Indeed, the equations for 18.4.55, 1.4.65 and 20.4.76 account for less than 50% of the variation in the extent of snowcover. Unfortunately, there is no clear pattern to the residuals which may have suggested new processes or variables. Seven of the eight sites, for example, for which the residual was more than one standard deviation from the mean on the 18.4.55 were located on the northern edge of the

Cairngorms. Three were over-predicted, however, and four under-predicted.

The original variables are quite successful in accounting for variation in the extent and depth of snowcover and, therefore, appear to represent the processes identified in Chapter 3. Results are highest for dates on which the period of melt is well advanced or when the depth of snow has been measured, which suggests that the variables represent the depth, rather than the extent, of snowcover.

7.6 REGRESSION ON THE PRINCIPAL COMPONENTS

It was concluded in Chapter 6 that the scores on the principal components can be interpreted as measures of natural potential. The validity of the scores as measures of natural potential can be tested by using the scores as input into regression analyses. If the scores are valid measures they should account for variation in the extent of snowcover.

A 1977 version of the BMDP "P4R" program (Dixon and Brown, 1977) was used with the original data listed in Appendix 7. All eleven components were used in the regression analysis (Johnston, 1980). Analyses were not undertaken on the depth of snow data because the size of the sample was too small (Morgan, 1978). Unfortunately, the size of the sample was different on each date, so a principal components analysis had to be undertaken for each set of data. The results, therefore, attempt to determine the validity of component scores as measures of natural potential. These scores, however, are different for each set of data and from the scores calculated and analysed in Chapter 6. This section, therefore, validates the method rather than the results derived from the the 54 site matrix.

The results are listed in Table 7.8. A notable feature of the results is that the coefficients of determination are very

Table 7.8: Results of the regression analyses on the principal components.

	R^2	F	p	Component No.	Component Variables	r
18.4.55	0.39	2.32	NS	5	2,3,10,8	0.36
				9	1,9,10	-0.33
				6	3,5,2,4	0.23
				1	5,11,4,2	0.19
				7	6,4,10,2	-0.17
				4	10,3,9,1	-0.16
1.4.65	0.41	5.92	0.01	2	10,6,3,5	-0.33
				7	2,1,6,9	0.32
				9	11,3,2	-0.31
				6	8,3,2	0.25
				8	2,8,1,3	0.21
25.4.68	0.88	22.54	0.001	3	5,6,9,4	-0.62
				2	10,1,9,4	-0.51
				4	11,4,7,10	0.34
				6	3,11,2	-0.28
				9	6,3,5,4	-0.21
20.4.76	0.48	6.64	0.01	2	6,7,9	-0.41
				5	4,7,6	0.38
				3	10,2,1	-0.26
				9	11,2	-0.20
				7	2,1,9,6	0.18
				11	10,6,4	0.16
13.4.81	0.64	10.07	0.001	5	3,2,8	0.58
				4	9,3,4,5	0.32
				1	11,10,5,4	-0.29
				8	10,11,1	0.27
				2	7,6,8	0.22

Variables:

1 Global radiation
2 Basin ratio
3 Gully side slope
4 Form ratio
5 Fetch
6 Top altitude
7 Topographic rise
8 Leeward slope
9 Snowdrift
10 Wind-drift
11 Topographic exposure

similar to those from regression on the original variables (see Table 7.6). This finding suggests that these results mark the limit of the ability of the original data and the scores to account for variation in the extent of snowcover on the five dates. To increase the coefficients of determination, the definition of the variables must be improved and new variables identified. To aid interpretation of the results, Table 7.8 also shows the variables with the highest loadings on each of the components and the correlations between the components and the extent of snowcover. The variables are shown in order of decreasing level of loading and can be compared with those for the PCA of all 54 sites in Chapter 6 (see section 6.3.2). Variables which are prominent in the components include top altitude, wind-drift, topographic exposure and basin ratio. These are quite similar to those identified as important in the full analysis in Chapter 6, and to those identified in the regression analyses of the original variables.

The null hypothesis that the coefficient of determination is zero can be rejected for 1.4.65 and 20.4.76 at the $p = 0.01$ level, and for 25.4.68 and 13.4.81 at the $p = 0.001$ level. The F-ratio of 2.32 for 18.4.55 is only significant at the $p = 0.10$ level. Although the results for 18.4.55 and 1.4.65 are relatively poor, those for dates on which the period of melt is well advanced (25.4.68, 20.4.76 and 13.4.81) are quite satisfactory. This finding confirms that the variables and the component scores represent the depth, rather than the extent, of snowcover, which suggests that the component scores are valid measures of natural potential. This point is supported by the argument in Chapter 3 that natural potential can be represented best by the depth of snow.

The test could be improved by collecting data on the depth of snow for all 54 sites used in Chapter 6 on several occasions. This data could then be used to verify the interpretation of the components and to validate a consistent set of scores. Further attempts to validate and verify the component scores will be undertaken in Chapters 8 and 9. The results of the regression analyses will be critically examined in Chapter 8.

7.7 CONCLUSIONS

1. The original variables accounted for between 43% and 85% of the variation in the extent of snowcover, and between 70% and 84% of the variation in the depth of snow. They do, subject to limitations in their definition and measurement, represent the processes that control the consistency of snowcover.
2. Top altitude, leeward slope, basin ratio and gully side slope figure prominently in all of the results.
3. The scores on the principal components accounted for between 39% and 88% of the variation in the extent of snowcover and are, therefore, valid measures of natural potential.
4. The coefficients of determination are highest for dates on which the period of melt is well advanced, i.e., when only deep deposits of snow remain, or when the dependent variable is the depth of snow. This suggests that the variables and the component scores represent the depth of snow more than the extent of snowcover.

5. Possible causes for the variation not accounted for are:

i. regional patterns in the supply of snow (e.g., snow shadows as storms cross the mountains);

ii. the definition of some variables (e.g., artificial boundary for each gully for the measurement of side slope, basin ratio and topographic exposure to be measured at the mid-point of each gully);

iii. the low correlations between the extent of snowcover and snowdrift, wind-drift and global radiation, and

iv. the definition of the dependent variable and its measurement.

6. The results compare favourably with those of studies undertaken in similar environments (i.e., where the drifting of snow is important).

The next chapter examines further the component scores as measures of natural potential by putting forward a technique for summing the scores. The results are then verified against the published opinions of skiers. After presenting a full validation and verification of the method, the results will be critically examined by analysing the assumptions upon which the method is based.

CHAPTER 8: VERIFICATION AND EXAMINATION OF THE RESULTS

8.1 INTRODUCTION

The aims of this chapter are to verify the results from the analysis of the morphology of sites and to critically examine the results by analysing the assumptions upon which the method is based. The chapter examines the scores on the principal components and comparisons are made with the opinions of skiers. The second section critically examines and interprets the results and attempts are made to give reasons for the variation which remained unaccounted for in Chapter 7.

8.2 VERIFICATION OF THE SCORES ON THE PRINCIPAL COMPONENTS

8.2.1 Introduction

In Chapter 3, it was argued that the scores on the principal components could be interpreted as measures of natural potential, and this was confirmed by the validation of the results in Chapter 7. This section summarises the relationship between the components and the consistency of snowcover, sums the scores to provide an overall measure of natural potential and verifies the results against the opinions of skiers.

8.2.2 Interpretation of the principal components

Although discussed in Chapter 6, the interpretation of the components will be summarised here to provide a context within which the scores on the components can be interpreted (a full analysis is given in section 6.2.2). Table 8.1 shows the five sites with the highest or lowest scores on each component.

The first component was thought to represent the entrapment

Table 8.1: Sites with high and low scores on the first five principal components.

	HIGHEST		LOWEST	
1	Clais nam Balgair (31)	3.305	Easan na Bruaich (10)	-3.706
	a' Choire Odhair (7)	2.811	Buidheannach Burn (51)	-3.219
	Fuaran Diotach (6)	2.046	a' Mhaim (26)	-2.968
	Meall Dubhaig (4)	2.000	Toul (26)	-2.769
	a' Gheoidh (41)	1.780	Coire an t-Sabhail (24)	-2.726
2	a' Choire Mhoir (23)	3.455	Coire an Chaisteil (46)	-3.292
	Clach n. Taillear (22)	3.176	Clais Mhor (43)	-2.006
	Feith Buidhe (17)	2.524	Iar-choire Sneach. (33)	-1.784
	Coire Dhondail (8)	2.348	a' Choire Ghuirm (32)	-1.744
	Derry Cairngorm (29)	1.492	a' Choire Chais (15)	-1.681
3	a' Choire Ghuirm (32)	4.218	a' Choire Odhair (7)	-2.780
	Buidheannach Burn (51)	2.445	Coire an Lochain (14)	-2.135
	Clach n. Taillear (22)	2.372	Creag Dubh (19)	-1.884
	Clais Bheag (45)	2.080	a' Choire Chais (15)	-1.514
	an t-Sneachda (33)	1.707	Creag an Leth-choin(13)	-1.481
4	Derry Cairngorm (29)	2.040	Coire Dhondail (8)	-3.912
	Iar-choire Sneach. (33)	1.869	Buidheannach (9)	-2.334
	a' Mhaim (26)	1.827	Coire an Chaisteil(46)	-1.968
	Derry Cairngorm (30)	1.582	Fhearnagan (3)	-1.605
	Coolah (40)	1.562	an Chram-alltain (2)	-1.591
5	na Ciste (16)	3.116	Gharbh-choire (39)	-2.289
	Fhearnagan (3)	1.766	Bhuidhe Mhoir (47)	-1.646
	a' Choire Chais (15)	1.635	a' Choire Mhoir (23)	-1.376
	a' Choire Ghuirm (32)	1.369	Toul (25)	-1.339
	a' Choire Ghuirm (12)	1.357	Coire an Chaisteil (46)	-1.206

of snow at a site and the drifting of deposited snow by the wind. Two types of site were identified:

1. those with relatively deep, incised basins and long fetch; and
2. those with shallow basins on exposed slopes with limited fetch.

This division of the sites into two main types was confirmed by the cluster analysis (see section 6.3.2) and the discriminant analysis (see section 6.4.2). Sites with high scores on this component are relatively deep and incised, and should have the more consistent snowcover of the two types owing to the creation of turbulence in the air and the high values of wind-drift and fetch (the influence of the other components being held constant). There is evidence to suggest that during warm, windy weather the creation of turbulence in the air may increase the rate of turbulent exchange (see section 3.2.3), so the rate of melt may be faster at sites with high scores (the influence of global radiation and altitude held constant). On the whole, however, it is assumed that sites with high scores will have the more consistent snowcover.

Sites with high scores on the second component have high values of top altitude, topographic rise and fetch, and average values of gully side slope. Sites with low scores have low values of top altitude, topographic rise and fetch, but have steep gully side slopes. The influence of top altitude, topographic rise and fetch on the extent of snowcover is generally positive and relatively strong (see Table 7.4). The steep gully side slopes at sites with low scores should entrap considerable amounts of snow but this would be outweighed by the low values of top altitude, topographic rise and fetch. Sites with high scores, therefore, are likely to have more consistent snowcover than sites with low scores (the influence of the other components being held constant).

Those sites with high scores on the third component have high values of global radiation and basin ratio and low values of snowdrift. Sites with low scores have low values of global radiation and basin ratio and high values of snowdrift. A combination of low global radiation and high snowdrift should favour consistent snowcover, although basin ratio has a positive, but weak, relationship with the extent of snowcover (see Table 7.4), which may limit the advantage of low global radiation and high snowdrift.

The fourth principal component is somewhat difficult to interpret. Sites with high scores have high values of leeward slope, wind-drift and global radiation, but low values of gully side slope and top altitude. The influence of leeward slope on the extent of snowcover is usually positive and relatively strong (see Table 7.4) so, together with high values of wind-drift, these sites should receive relatively large quantities of snow. The high values of global radiation and low top altitude, however, suggest that their ability to retain snow will be poor. Sites with low scores should retain snow relatively better than sites with high scores and, together with the higher values of gully side slope, should have the most consistent snowcover. The adverse effect of low values of leeward slope and wind-drift, however, should be borne in mind.

Sites with low scores on the fifth component have high values of topographic rise and leeward slope. The influence of these two variables on the extent of snowcover is generally positive (see Table 7.4). These sites, however, tend also to have high values of form ratio, which can have an adverse influence on the extent of snowcover (Table 7.4).

In summary, sites with high positive scores on the first two components and high negative scores on the third, fourth and fifth components should have the most consistent snowcover. Only one site - Allt a' Mharcaidh (1) - satisfies this requirement. All other sites have at least one score which is not conducive to the consistency of snowcover. This confirms the conclusion in Chapter 5 that few sites within the study area would have good supply <u>and</u> entrapment <u>and</u> retention characteristics.

As the components are independent of each other and their relationship with the consistency of snowcover described, the scores can be further analysed if they are summed in a way which expresses the influence of each component on the consistency of snowcover. Table 8.2 shows the scores on the first five components for Allt a' Choire Ghuirm (5). The interpretation

Table 8.2: Scores on the components for Allt a' Choire Ghuirm (5).

Component	Score	Converted score	Summed score
1	+1.213	+1.213	+1.213
2	-0.553	-0.553	+0.660
3	-1.294	+1.294	+1.954
4	-0.617	+0.617	+2.571
5	+0.008	-0.008	+2.563

above suggested that high positive scores on the first two components and high negative scores on the three others would be the best combination of scores. The middle column in Table 8.2 shows the scores converted to beneficial (positive) and not beneficial (negative) to the consistency of snowcover. A score of -1.294 on the third component, for example, should have a positive or beneficial relationship with the consistency of snowcover (see earlier). The converted scores can now be summed (right column) to show an overall measure of natural potential (i.e., a high negative score may represent consistent snowcover). Sites with high positive summed scores, therefore, should have the most consistent snowcover. Table 8.3 lists the summed scores for all 54 sites and ranks them accordingly (all component scores are listed in Appendix 9).

Table 8.3: Summed scores of the first five components (site numbers in brackets).

Rank	Site	Score	Rank	Site	Score
1	Coire Dhondail (8)	6.961	28	Creag Dubh (19)	-0.214
2	a' Choire Mhoir (23)	6.204	29	Fhearneasg (54)	-0.216
3	Choire Odhair (7)	5.077	30	C. an t-Sabhail (24)	-0.415
4	Feith Buidhe (17)	4.759	31	Beanaidh Bheag (11)	-0.427
5	Cl. nam Balgair (31)	3.843	32	an Chaisteil (46)	-0.439
6	a' Mharcaidh (1)	3.622	33	Lochain Uaine (28)	-0.495
7	Derry Cairngorm (29)	2.758	34	Beinn Mheadhoin (20)	-0.556
8	Chram-alltain (2)	2.688	35	Coire Lagain (48)	-0.778
9	Fuaran Diotach (6)	2.640	36	Toul (25)	-0.801
10	Choire Ghuirm (5)	2.563	37	C. an Lochain (14)	-0.835
11	Buidhe Mhoir (47)	2.077	38	na Ciste (16)	-0.962
12	a' Gheoidh (41)	1.936	39	Coire Dhuibh (52)	-1.114
13	Gharbh-choire (39)	1.903	40	Derry Cairngorm (30)	-1.324
14	Bheal. Bhuidhe (50)	1.417	41	Choire Ghuirm (12)	-1.358
15	Leth-choin (13)	1.387	42	Beinn Mheadhoin (21)	-1.423
16	Coire Bhuidhe (18)	1.296	43	Buidheannach (9)	-1.682
17	Meall Dubhaig (4)	1.189	44	Choire Chais (15)	-2.016
18	Fhearnagan (3)	1.187	45	Clais Mhor (43)	-2.064
19	C. nan Taillear (22)	1.153	46	an t-Sneachda (34)	-2.123
20	Coolah (40)	0.672	47	Derry Cairngorm (29)	-2.425
21	na Beinne (35)	0.521	48	C. Chlachaich (42)	-2.872
22	C. Ruairidh (36)	0.450	49	Choire Ghuirm (32)	-3.413
23	Coire Fionn (38)	0.418	50	Clais Bheag (45)	-3.619
24	an t-Sluichd (37)	0.358	51	na Bruaich (10)	-4.350
25	an t-Saighdeir (53)	0.132	52	a' Mhaim (26)	-5.928
26	a' C. Mhoir (44)	-0.056	53	I.c. Sneachdach (33)	-5.990
27	an Tuirc (49)	-0.128	54	Buidheannach (54)	-6.078

8.2.3 Interpretation of the summed scores

The sites with the best summed scores are Allt Coire Dhondail (8), Allt a' Choire Mhoir (23), Allt a' Choire Odhair (7), the Feith Buidhe (17) and Allt Clais nam Balgair (31). Sites with the worst summed scores are Buidheannach Burn (51), Allt Iar-choire

Sneachdach (33), Allt a' Mhaim (26), Allt Easan na Bruaich (10) and Allt Clais Bheag (45). The first five sites are located towards the centre of the Cairngorm Mountains and have high values of topographic rise, leeward slope, top altitude, snowdrift and wind-drift, and long fetch. Sites with the lowest values have shallow gullies and basins, low top altitude, high global radiation and low values of snowdrift and wind-drift.

The five sites in Glen Feshie are, on the whole, the best group of sites studied, although a number of individual sites have a summed score which is higher. The main disadvantages of the sites in Glen Feshie are low values of topographic rise, leeward slope, snowdrift and wind-drift (although fetch is consistently above average). The Cairngorm Area Report (Scottish Development Department, 1967; p.53) concluded that Allt a' Mharcaidh (1, rank 6th) had "...considerable potential for future development". Allt a' Choire Ghuirm (5, 10th), Allt Meall Dubhaig (4, 17th) and Allt Fhearnagan (3, 18th) are well known to skiers as providing good skiing (Firsoff, 1965; Scottish Development Department, 1967; Slesser, 1970; Watson, 1975). Allt a' Choire Ghuirm is often thought by skiers to have the most consistent snowcover of the three and this is confirmed by the combined scores in Table 8.3.

The Scottish Development Department (1967) also concluded that Alltan ne Beinne (35, 21st), Allt Coire Ruairidh (36, 22nd) and Allt a' Choire Ghuirm (32, 48th) on Beinn a' Bhuird offered a "...potential for winter sports similar to that of the Cairn Gorm group" (p.54). Slesser (1970) suggested that the mountain was a

"...superb snow-holding hill" and that the south-east slopes (Allt Iar-choire Sneachdach 33, 53rd; Allt an t-Sneachda 34, 45th) "...offer the finest open skiing in Scotland" (p.52). The Langmuir Ski Group (1979) came to a similar conclusion. The combined scores in Table 8.3, however, do not confirm this.

Sites 32, 33 and 34 have low values of top altitude, snowdrift and wind-drift and high values of global radiation. The depth of snow in each gully must be considerable, therefore, to survive the poor characteristics for retention. The steep gully side slopes (see Appendix 7) must entrap large quantities of snow for this to happen. It should also be noted that the snowcover is more consistent in the upper reaches of these basins (above the top altitude of the gullies) and usually survive until the autumn (Watson, 1975). Firsoff (1965) noted that Beinn a' Bhuird and Ben Avon were often snow-covered when the western Cairngorms were not and suggested that this was because the western Cairngorms are exposed to warm and wet SW gales which become drier as they cross the massif before reaching Beinn a' Bhuird and Ben Avon.

Braeriach is often thought to have the most consistent snowcover of any mountain in Scotland (Hunter, 1964; Langmuir Ski Group, 1979), although it is the north-facing corries which are often assumed to have the best snow. This is not confirmed by the scores in Table 8.3. For a large proportion of their length, Beanaidh Bheag (11, 30th) and Allt a' Choire Ghuirm (12, 40th) lie below 750m and it is only above this altitude that the snowfields begin. The definition of a "site" (see Chapter 1) is critical, therefore, particularly as it controls the location of the mid-point and so the values of basin ratio and topographic exposure. It should be noted, however, that in the regression analyses for 18.4.55, 1.4.65 and 13.4.81 the equations over-predicted the extent of snowcover at these two sites (i.e., the actual extent of snowcover was less than that which could be expected from the values on the variables).

At the public inquiry into proposals to develop facilities for downhill skiing in Coire an t-Sneachda, Coire an Lochain (14, 36th) and Lurchers Gully (13, 15th) at Cairn Gorm it was argued that snowcover in the first two areas was unreliable for most of the season. When the first five components are examined this is not confirmed (except if Lurchers Gully and Coire an Lochain are compared). If the fifth component is ignored, however, Coire an Lochain (14, 0.396) has a score lower than that for Allt na Ciste (16, 2.154) and Lurchers Gully (13, 1.635). Full examination of this, and the scores for Coire an t-Sneachda and Coire Laogh Mor, in relation to the extent of snowpatch vegetation will be given in Chapter 9.

Allt a' Choire Chais (15, 43rd) and Allt na Ciste (16, 37th) have been developed for skiing, and a ski lift has been built in the basin of Allt Coire Fionn (38, 23rd). Some 42 sites have higher combined scores than Allt a' Choire Chais, 36 sites for Allt na Ciste and 22 sites for Allt Coire Fionn. This finding suggests that many sites have snowcover which is more consistent than that at sites already developed for skiing. It was admitted at the public inquiry (Scottish Development Department, 1983) that below 760m, the snow in Allt a' Choire Chais is unreliable, while above 760m the snow is much more reliable (although this may, in part, be due to snowfencing). Allt na Ciste holds snow well into the summer as the snow builds up to great depths during the winter (Watson, 1975). The low combined score (-0.962) is largely the product of a high score on the fifth component (+3.116), whose influence was assumed to be negative.

8.2.4 Summary

The results, and their interpretation, show clearly that one of the advantages of the method is the ability to justify a particular score, i.e., why one site should have more consistent snowcover than another site. Allt Coire Dhondail (8, 1st), for example, has a long fetch, high top altitude, steep gully side slopes and low global radiation and average values of topographic rise, leeward slope, snowdrift and wind-drift. Buidheannach Burn (51, 54th) has very high global radiation, shallow gully side slopes, a very limited fetch and low values of snowdrift and wind-drift. Verification, however, is restricted by the limitations of the opinions of skiers (see section 2.4.4) which makes it difficult to verify the results accurately. It appears, however, that the results challenge many of the opinions and beliefs that have been long-held by skiers.

8.3 CRITICAL EXAMINATION OF THE RESULTS

8.3.1 Introduction

Although it was concluded in Chapters 6 and 7 and in section 8.2 that the component scores were valid measures of natural potential, a large part of the variation in the extent of snowcover was unaccounted for by either the variables or the components. The method is based on four main assumptions which may be responsible for this. This section examines these assumptions in the light of the results to date and additional data on snowlines, snowpatches, former glaciers and drift patterns created by the wind. The four assumptions are:

1. that the amount of precipitation remains constant across the study area (the influence of altitude and upwind terrain being held constant);

2. that the wind direction is the same for each site;

3. that the extent of snowcover is equivalent to the depth of snow and hence the consistency of snowcover, and

4. that the variables measured at the source and mid-point of the gully are representative of the gully as a whole.

8.3.2 Amount of precipitation

Top altitude, topographic rise and leeward slope were identified to represent the increase in the amount of precipitation with altitude and its depletion upwind of a site, although no data are available on the actual amounts of precipitation at sites within the study area. There is evidence (see section 4.5.2) which points to the existence of snow "shadows", where the amount of precipitation varies considerably as storms cross the study area. If some sites receive more precipitation than other sites the measurable influence of the other variables would be reduced. The importance of this can be examined using data on snowlines, snowpatches and the location of former glaciers.

A. Snowlines.

Within the study area, snowlines have been observed consistently only on Ben Macdui, and few data are available for other mountains in Scotland (see section 2.4.2). Additional observations of snowlines were commissioned from several local people (most of whom were observers for the Meteorological Office), for the winters of 1983/4 and 1984/5. The snowline was observed at 0900 hours and taken to be the altitude at which 50% or more of the ground was covered by snow. On days when low cloud obscured the snowline, the altitude was interpolated with reference to conditions on preceding and succeeding days and the weather recorded at the observation station. Table 8.3 shows the mountains observed, their aspect and altitude and the locations from which they were observed. The snowlines were converted into the number of days with snow lying at certain altitudes to allow for easier comparison of areas and seasons. Records from Aviemore, Achnagoichan and Derry Lodge are collected for the Meteorological Office already, although no observations were taken from the last two sites in 1984/5.

Table 8.3 Location, aspect and altitude of mountains observed.

Station	Mountain	Aspect	Altitude
Aviemore	NW Cairngorms	NW	1296
Achnagoichan	Ben Macdui	NW	1309
Braemar	Ben Avon	SE/SW	1112
	Morrone	NE	859
Dalwhinnie	Drumochter hills	NW	941
Derry Lodge	Ben Macdui	SE	1309
Kingussie	Glen Feshie hills	NW	1051
Lagganlia	Creag Mhigeachaidh	NW	742

The aim was to compare the duration of snowcover on mountains in the western Cairngorms with those in the eastern Cairngorms. If snow shadows exist, differences in the duration of snowcover between the two areas should be apparent.

In 1983/4, almost 50% of total snowdrift came from the SE. The storms on the 21.1.84, 23.1.84, 23.3.84 and 24.3.84 accounted for 20.5% of total snowdrift and came from the SE. Total precipitation during the winter was 596.2mm at Braemar and 386.6mm at Lagganlia. This pattern of precipitation is evident in the duration of snowcover on the mountains. Figure 8.1 shows the data for the winter of 1983/4. The difference in the duration of snowcover between Ben Avon/Morrone and the other mountains is very distinct, particularly below an altitude of 900m. The duration of snowcover was generally similar for all sites in the western Cairngorms, but much greater below 900m in the eastern Cairngorms. This difference was evident particularly in February and March, which suggests that the amount of snowfall during the storms in January was greater in the latter area.

The observations for Achnagoichan and Glen Feshie were not included because of discrepancies with fieldwork notes. In April, for example, Ben Macdui and Braeriach had a 50% or more cover of snow only above 600m and not the 450m recorded by the observer at Achnagoichan.

The difference in the duration of snowcover between the two massifs at 600m was 45 days, a difference also evident between Ben Avon and Ben Macdui which are only 15km apart. The suggestion of Firsoff (1965) that Beinn a' Bhuird and Ben Avon are sheltered

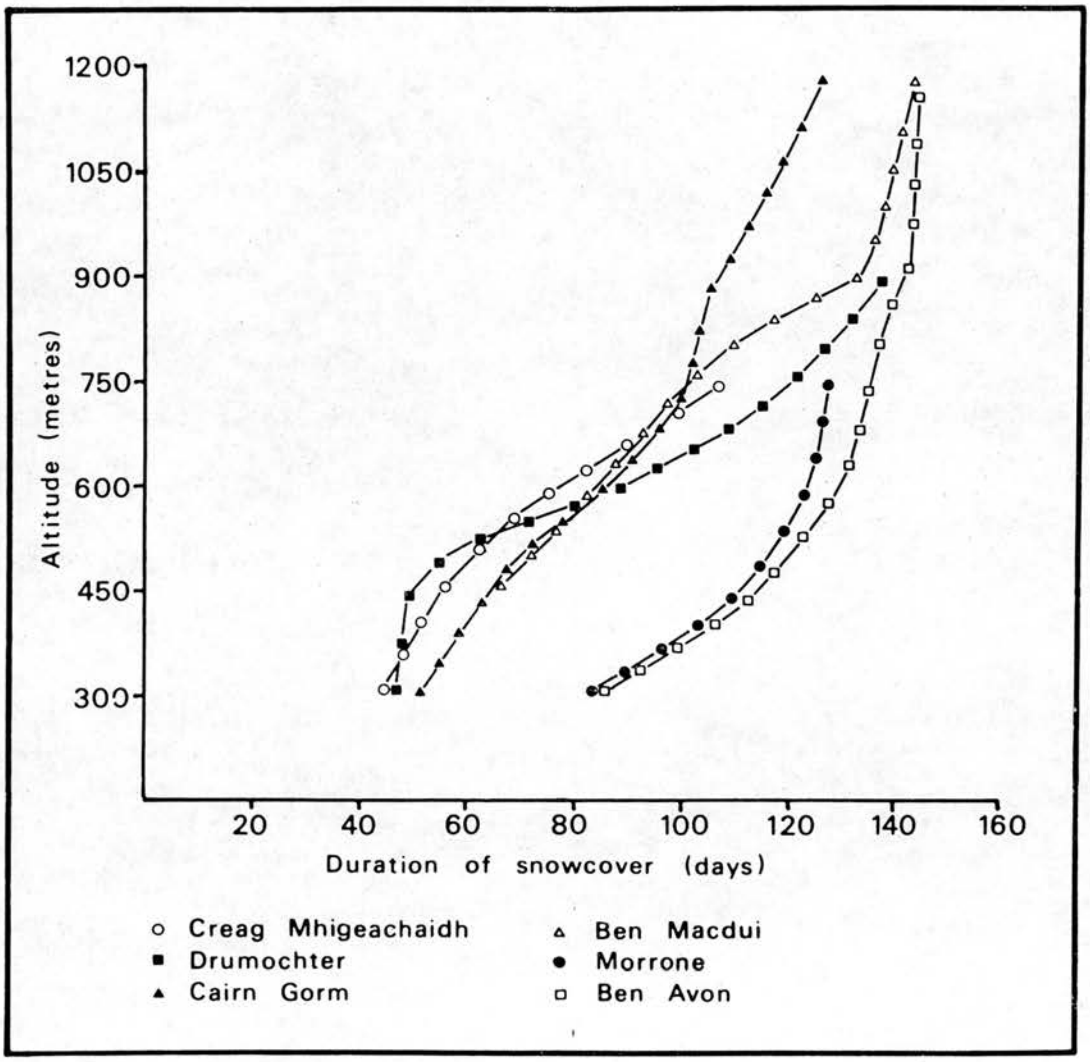


Figure 8.1: Duration of snowcover on certain mountains in the winter of 1983/4.

from warm winds from the SW by the western Cairngorms, together with the differences in precipitation, may account for this. These results are confirmed by the depth of snow measured in gullies in both areas during April, with greater depths of snow measured in the SE Grampians (see Chapter 7 and Appendix 8).

Some 58.9% of total snowdrift in 1984/5 came from the west, which is very close to the mean of 56.8% for the last 30 winters. Four storms accounted for 32% of the total snowdrift, two of which came from the ESE, one from the WSW and the other from the

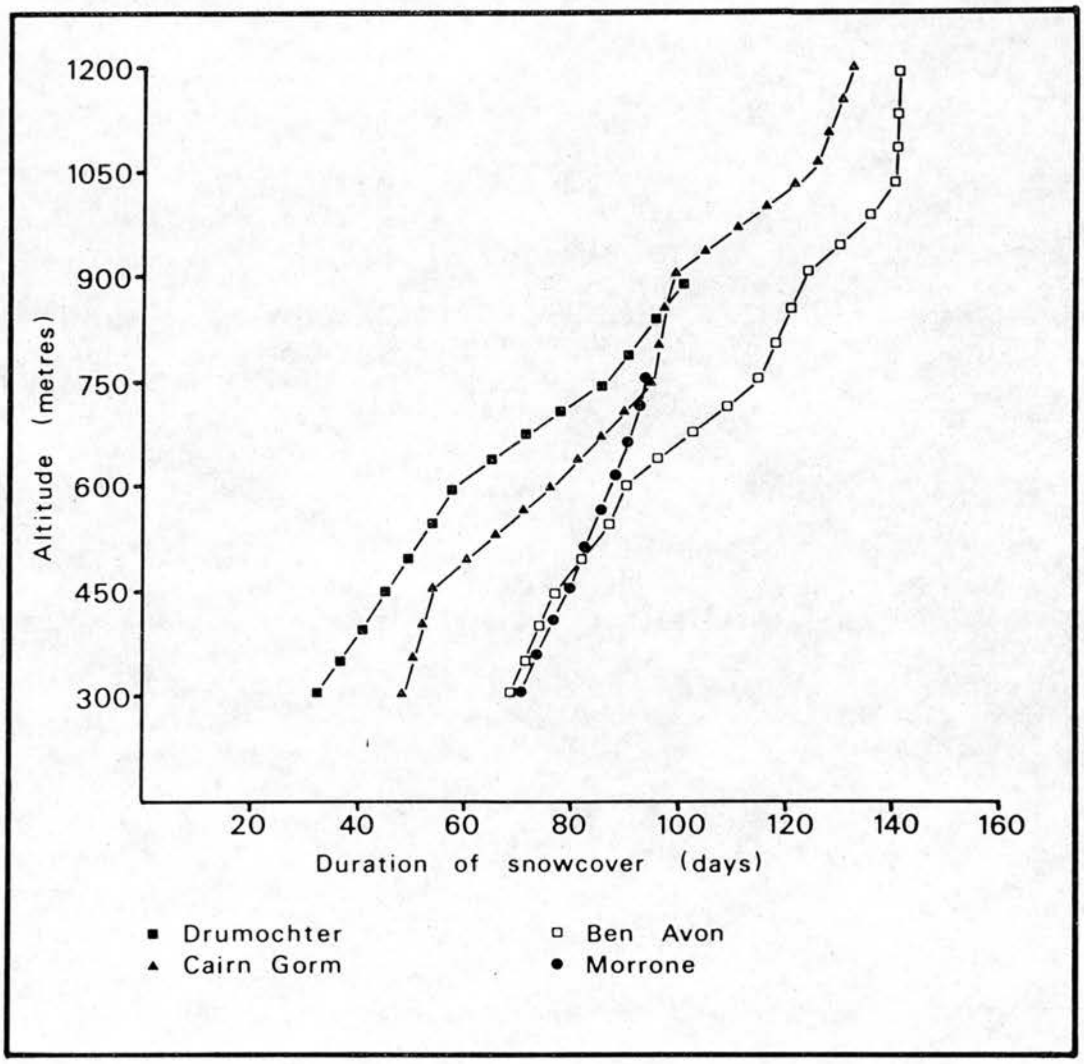


Figure 8.2: Duration of snowcover on certain mountains in the winter of 1984/5.

WNW. Total precipitation was 340.8mm at Braemar and 262.2mm at Lagganlia. There were several thaws during the season which prevented the build-up of substantial deposits of snow (i.e., the opposite situation to 1983/4).

Figure 8.2 shows the duration of snowcover in 1984/5, which was generally less than in 1983/4 on Ben Avon and Morrone, but very similar in the Cairngorms. The differences between the two

750m, the number of days with snowcover is very similar between the two winters. During fieldwork in April 1985, however, the depths of snow in gullies in the SE Grampians were much less than in 1984 and generally less than the depths measured in the Cairngorms (see Appendix 8).

The snowlines observed in the winters of 1983/4 and 1984/5 confirm the existence of regional differences in the amount of precipitation, although this is evident more in 1983/4 than in 1984/5.

B. Snowpatches

There are three main types of snowpatch (King, 1968): (1) semi-permanent (those which survive most years but are not permanent); (2) very late-lying (those that last usually until late-July or early August); and (3) late-lying (those which last until mid-June). Previous surveys have concentrated on very late-lying or semi-permanent snowpatches (e.g., King, 1968; Manley, 1969; Hudson, 1976; Spink, 1978; and one exception: Ballantyne, 1985). As noted in Chapter 3, the sites occupied by semi-permanent snowpatches should offer the best combination of supply, entrapment and retention characteristics of any sites within the study area. In most years, therefore, the location of semi-permanent snowpatches are very similar and so provide little information on the characteristics of the supply of snow during the previous winter.

Much more information can be inferred from late-lying snow-patches because they are greater in number and are located throughout the study area, and so tend to reflect the characteristics of the supply of snow during the winter. Surveys of late-lying patches were made in June, 1983 and June, 1984.

If the amount of precipitation was higher in the SE Grampians than in the Cairngorms, the number of snowpatches should be greater and their altitude lower in the former area. If the wind regimes were different between the winters then the snowpatches within a specific area should be in different locations. In June 1984, the mean altitude of 64 snow patches in the Glenshee area was 853m, while that for 40 patches in the Cairn Gorm area was 950m. This appears to confirm that there was greater precipitation in the SE Grampians than in the Cairngorms in 1983/4.

Figure 8.3 shows the location of snowpatches on Glas Maol in June, 1983 and June, 1984 respectively. The location of snowpatches between years can be compared on the headwall of the Glas Choire on Glas Maol. In 1982/3, when 79.9% of total snowdrift came from the west a cornice developed on the east-facing side of the corrie (Figure 8.3, point A). In 1983/4, when 58.5% of total snowdrift came from the east, the cornice developed on the west facing slope of the corrie. Similar differences between the two years can be found at points B, C and D.

These findings suggest that the amount of precipitation can vary considerably across the study area and that the patterns of the supply of snow can differ markedly from winter to winter and influence the location of snowpatches.

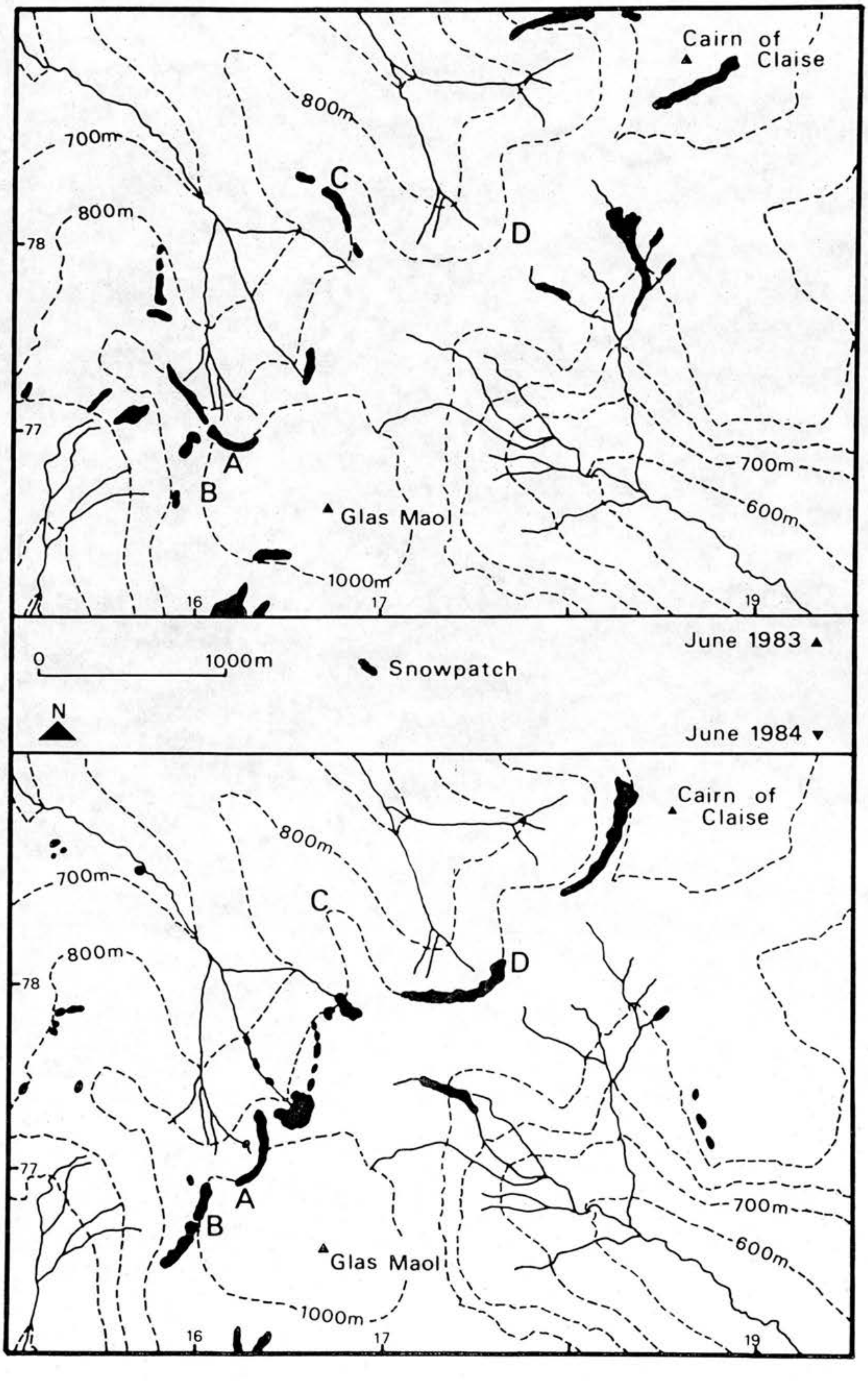


Figure 8.3: Location of late-lying snowpatches on GlasMaol/Carn an Tuirc in 1983 and 1984.

C. Former glaciers.

A further source of evidence in support of sharp differences in the amount of precipitation across the study area, is that provided by the location and characteristics of former glaciers. Sissons and Sutherland (1976) and Sissons (1980) discussed the extent of former glaciers in the SE Grampians and the Cairngorms and made inferences about the climate which existed at the time of the glaciers. The altitude of the firn-line of the glaciers rose at a steady rate north-westwards from the edge of the Highland Boundary Fault, where it was almost 500m, to almost 1000m on Lochnagar. A similar rise in the altitude of the firn-line to the NW was also observed in the Cairngorms. From this evidence the inference was made that in this area of Scotland snowfall was associated mainly with south to south-east air streams preceding warm and occluded fronts. Precipitation in the Cairngorms was lower than it is at present.

Sissons (1980, p.37) suggested that this pattern is "...frequently paralleled by the snowline today during and after a spell of SE winds in winter or early Spring". This is confirmed by the duration of snowcover in 1983/4 (Figure 8.1), and the location of snowpatches observed in June 1984.

It is quite obvious that snow "shadows" do exist within the study area, and this may well influence the extent and depth of snowcover measured at different locations. Data on the amounts of precipitation involved (with the exception of the data for the weather stations at Braemar and in the Spey Valley) or on the rate of the decrease in the amount of precipitation as storms cross the massif are not available. It is essential that attempts are made to collect data that are suitable (see Chapter 10). Although this research was concerned with the relative supply of snow rather than the absolute amount, the latter would affect the outcome of the regression analyses in Chapter 7 and may also "mask" the influence of the variables on the extent of snowcover in each gully.

8.3.3 Direction of the wind

The paucity of data on wind speed and direction in the study area restricted the type of data which could be used. As new data on wind direction and speed could not be collected, the geostrophic wind was measured (see section 4.3.1). Although the speed and direction of the geostrophic wind could be measured, its spatial resolution is controlled by the distance between the isobars. Although the speed of the geostrophic wind was quite strongly correlated with surface wind speeds recorded at the automatic weather station on the summit of Cairn Gorm (see section 4.3.2), the speed and direction of the geostrophic wind will be modified by the morphology of the land surface. This modification may have important consequences for the measurement of snowdrift and wind-drift, the deposition of snow along the length of each gully and the melting of snow through turbulent exchange.

A study in the Cairngorms and/or SE Grampians of actual surface winds (i.e., similar to that by Pedgley (1971) in Snowdonia) is not possible because few people reside on the massif. Observations would be possible in some of the larger glens (e.g., Glen Clunie, Glen Feshie, Glen Shee), but not for large parts of the massif, such as land above 400m. Although Holroyd (1970) used the deformation of trees as indicators of local wind directions on a massif in North America, such a study would be of very limited use in the Scottish Highlands as the treeline rises to 600m only (Pears, 1965).

Wind directions could be inferred from individual snowdrifts after snowstorms, provided that aerial photographs at a suitable scale were available. Minnich (1984) used oblique aerial photographs taken after three snowstorms to map the snowdrifts on Mount San Gorgonio in California. As SW winds are predominant in southern California, the findings could be taken as representative of a much longer period of time than for the three dates. In the study area, where no wind direction is dominant (see section 4.3.2), a large number of dates would need to be surveyed.

A set of aerial photographs taken on the 4.2.55 (see Table 2.6) show a large number of drifts on the summit plateaux of the Cairngorms. Figure 8.4 shows the main wind directions inferred from these drifts. There are two main directions, one north-easterly and the other north-westerly. It is not clear whether this is due to the influence of topography or of two separate snowstorms. On the 1st to the 3rd of February 1955, small amounts of snow fell in winds from the SE (see Appendices 2 and 4) so the drifts would point NW. Wind-drift on the 4th was associated with winds from the SW (with speeds of up to 18.5m/s), so drifts would point NE. This would explain the two different directions inferred from the snowdrifts. Unfortunately, no drifts were

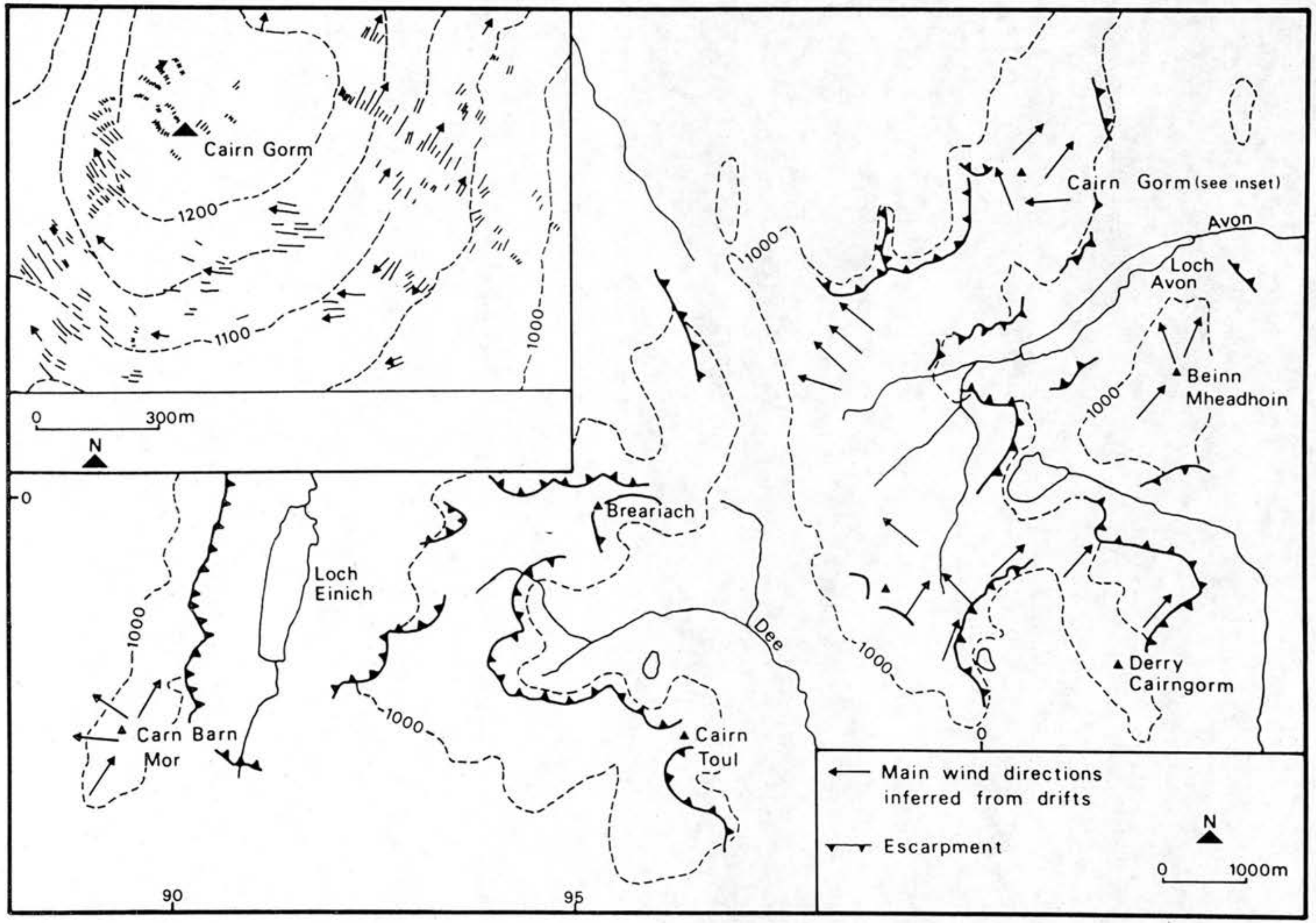


Figure 8.4: Main wind directions inferred from drift patterns observed on the 4.2.55.

visible on the Braeriach/Cairn Toul plateau or on the lower slopes of the mountains. A full examination of the method would require a larger sample of dates and aerial photography of a better quality so that the lower slopes of the mountains could be studied.

A further source of data might be the location of snowdrifts after each storm (these would be located on leeward slopes, so the wind direction could be inferred from this) and the location of late-lying snowpatches. If most snowpatches, for example, were located on slopes facing NW and only a few were on slopes facing SE, then local wind directions may be the cause. Similarly, if a snowpatch is found in the same location after two winters with very different wind regimes then, for some reason, local wind directions are similar at that site regardless of the general directions of the wind.

All of the above methods require much more data than is available at present. Even then, this data could only be used as a "corrective factor" to the direction of the geostrophic wind. The important requirement remains a value of wind speed and direction on each day.

8.3.4 The dependent variable

To validate the results, the extent of snowcover in each gully was used as the dependent variable. The extent of snowcover was chosen because of the nature of the data available and the logistical problems associated with the measurement of the depth of snow (see section 7.2). It was concluded that the coefficients of determination were highest for dates on which the period of melt was well advanced (e.g., 25.4.68, 13.4.81) or when the depth of snow was used (e.g., April 1984 and 1985).

It was hypothesised in Chapter 3 that the site(s) with the most consistent snowcover would have the best combination of values on the variables identified to represent the processes that control the consistency of snowcover. The sites of very late-lying and semi-permanent snowpatches are likely to have the best combination of values. Future research could test this hypothesis more rigorously by analysing data measured at the location of these snowpatches. A problem, however, would be to determine why these locations had snowpatches and why similar locations did not, i.e., some system of sampling would need to be employed so that sites with snowpatches and those without were analysed, otherwise the regression analyses would be biased towards the location of the snowpatches.

8.3.5 Definition of the variables

The limitations of the definitions of some of the variables were noted in Chapter 5. As defined in Chapter 1, a "site" is composed of a drainage basin and a gully and, therefore, is three dimensional. The researcher simplified this problem by defining some variables to be measured at the mid-point or source of the gully (e.g., basin ratio, topographic exposure, snowdrift, fetch). Several of these variables, however, had poor correlations with the extent of snowcover (Chapter 7). Three problems may account for this.

First, the main problem is whether or not the variables are representative of the gully or basin as a whole. This does not apply to gully side slope as it was measured for a number of transects and summed, or form ratio which is measured for the basin as a whole. Basin ratio and topographic exposure, which were measured at the mid-point of each gully, could be measured at several points along the gully and a mean value used. This might make them more representative and prevent the problems noted in Chapter 5 (see sections 5.2.2 and 5.2.11).

Second, it was assumed in Chapter 3 that sites with a high value of topographic exposure and a low value of basin ratio would not create turbulence in the air and so would not induce drifting. Sites with such values, however, tend to be located on exposed slopes where the gully provides the main obstacle to drifting snow and, because of this, snow could drift into the gully along its length. In deep and incised basins the gully might be "starved", with snow being deposited on headwalls and lee slopes within the basin. There might be a balance, therefore, between the increased drifting of snow in basins that are deep and incised and the high efficiency of gullies on exposed slopes in the entrapment of snow.

Third, the influence of topographic exposure and basin ratio may be "masked" by more important processes which have influenced the extent of snowcover. Sites with high values of topographic exposure and low values of basin ratio tend to be located more towards the centre of the Cairngorm Mountains. It has been suggested previously that the amount of precipitation may be greater in this area because of the high altitude of the surrounding mountains. Topographic rise and leeward slope (both related more strongly to the extent of snowcover) are higher for sites in this area than on the perimeter of the massif. The processes that they represent may provide greater amounts of snow in this area and so these gullies would have deep snow and higher values of the extent of snowcover.

The analysis of winter weather (Chapter 4) was used to provide data on snowdrift and wind-drift but suffered from several limitations. The geostrophic wind has too large a spatial resolution for individual sites and the calculated speeds are likely to be consistent, but slight, overestimates owing to the use of a single value for the density of air (see section 4.3.2). Under cyclonic conditions the speeds are likely to be underestimated because the gradient wind force was excluded. The amount and type of precipitation at 800m was predicted from data collected at low altitude which is open to four sources of error (see section 4.4) which are, however, relatively minor. Snowdrift was calculated from classes of precipitation and wind speed which assumed that their relative importance for the drifting of snow increased in a linear fashion. Such data as exist suggest, however, that the relationship is exponential.

These limitations are likely to underestimate, therefore, the importance of snowstorms on the supply of snow and the extent of snowcover at each site, particularly if the storms were associated with "snow shadows". As noted in Chapter 4, knowledge of these storms is very limited and offers a useful avenue, therefore, for research in future. Emphasis must be placed on the collection of data at higher altitudes if improvements are to be made to the measurement of snowdrift.

8.3.6 Summary

As a first attempt at identifying sites with the most consistent snowcover, several assumptions were required to enable the work to proceed within the constraints of time. These assumptions simplified several areas of difficulty but are thought to be largely responsible for the variation in the extent of snowcover not accounted for by the variables or components. The main problem facing the solution of these assumptions is the paucity of data on the amount of precipitation, the speed and direction of the wind and the depth of snow at individual sites. These data should be collected at a number of sites over a period of years. Areas for future research are suggested in Chapter 10.

8.4 CONCLUSIONS

1. The technique of converting the sign of each principal component to fit its relationship to the dependent variable and then summing the scores to provide an overall measure of potential is a useful one for planners and decision-makers. The sites can be ranked from the one with the most consistent snowcover to the one with the least and they can be easily compared.

2. The summed scores challenge many of the published opinions of skiers. The method is verifiable and objective, however, and its results can be justified by referring back to the original data.

3. The method is based on four assumptions that are thought to be largely responsible for the variance left unaccounted for in Chapter 7. The removal of these assumptions requires more data being collected on actual amounts of precipitation and wind speed

and direction at specific sites.

The next chapter illustrates the potential uses of the method in particular situations which both planners and decision-makers have had to deal with during the last four years.

CHAPTER 9: APPLICATION OF THE METHOD

9.1 INTRODUCTION

The preceding chapters produced four main types of information: (1) the loadings and scores on the principal components; (2) a classification of the sites; (3) classification functions, and (4) regression equations for predicting the extent or depth of snowcover on particular dates. This information can be used to meet some of the requirements of planners and decision-makers (see Chapter 2), including the identification of sites with the most consistent snowcover and the comparison of one site with other sites. The results have been validated with reasonable success and verified against the published opinions of skiers. The component scores were concluded to be quite accurate measures of natural potential.

The aim of this chapter is to illustrate the possible uses of the method by planners and decision-makers by applying it in two small case studies. Regression equations are developed by which the scores on a principal component for any site can be predicted and the classification functions developed in Chapter 6 are used to allocate new sites to their appropriate classes.

9.2 DEVELOPMENT OF THE REGRESSION EQUATIONS

The principal components analysis in Chapter 6 was undertaken on a sample of 54 sites chosen at random from a total population of 180 sites. The scores for other sites could be calculated by enlarging the size of the sample and re-running the analysis, although if a user did not have access to a computer this would not be possible. Multiple regression analysis can be used, however, to derive equations by which the scores on the components can be predicted for any site within the study area (White, 1979). The dependent variable is the score on a component and the independent variables are those identified in Chapter 3 and listed in Appendix 7.

As all variables have a loading on each component, the regression analysis will be internally consistent such that no variation will remain unaccounted for. A limited sample of 50 sites was used, therefore, so that the accuracy of the equations could be tested on the four sites remaining. Table 9.1 shows the correlation coefficients between the original variables and the first five components. Although the first five components only are used here (as they account for 75% of the variation), equations could be developed for all eleven components.

Table 9.1: Correlation coefficients between variables and component scores

Component	1	2	3	4	5
Global radiation	0.04	0.19	0.73	0.36	0.08
Basin ratio	0.49	-0.23	0.56	-0.05	0.06
Gully side slope	0.42	-0.51	0.19	-0.39	-0.11
Form ratio	0.68	-0.00	-0.10	-0.15	-0.56
Fetch	0.70	0.51	0.06	0.03	0.15
Top altitude	-0.09	0.73	0.11	-0.37	0.24
Topographic rise	-0.29	0.51	0.35	-0.33	-0.61
Leeward slope	-0.19	-0.02	0.36	0.68	-0.32
Snowdrift	0.45	-0.11	-0.56	0.29	-0.26
Wind-drift	0.63	0.43	-0.18	0.40	0.01
Topographic exposure	-0.80	0.26	-0.27	0.12	0.05

Variables with high loadings in Table 6.1 have the highest coefficients in Table 9.1. The correlation coefficients are in general less (in absolute value) for the higher order components.

Table 9.2 lists the regression equations which can be used to

Table 9.2: Regression equations for predicting scores on the principal components

	1	2	3	4	5
1	0.00093	0.00258	0.01160	0.00627	0.00217
2	5.80400	3.16700	8.24900	-0.86560	2.56300
3	0.04750	-0.07710	0.03310	-0.07110	-0.02170
4	2.85700	0.29300	-0.69500	-1.04400	-3.73500
5	0.00034	0.00032	-0.00004	0.00002	0.00014
6	-0.00025	0.00547	0.00054	-0.00321	0.00192
7	-0.00150	0.00305	0.00213	-0.00236	-0.00514
8	-0.00030	-0.00006	0.00055	0.00116	-0.00073
9	0.02410	-0.00463	-0.03940	0.02300	-0.02130
10	0.01950	0.01800	-0.00778	0.01643	0.00279
11	-0.01090	0.00473	-0.00548	0.00223	--------
I	-1.77500	-9.37600	-6.85200	-0.90800	6.23700
R	1.00	1.00	1.00	1.00	1.00
SE	0.003	0.002	0.0014	0.001	0.015

1 Global radiation
2 Basin ratio
3 Gully side slope
4 Form ratio
5 Fetch
6 Top altitude
7 Topographic rise
8 Leeward slope
9 Snowdrift
10 Wind-drift
11 Topographic exposure
I Intercept
R Coefficient of determination
SE Standard error of the estimate

predict the score on a component for any site. The accuracy of these equations in predicting scores on the principal components is shown in Table 9.3, with the predicted and actual scores for the four sites removed at random. The predicted and actual scores are almost identical, although the predicted scores on the fourth and fifth components are more than two standard errors from the actual values. As the coefficients are in general less (in absolute value) on these components than on the first three, the predicted scores may be relatively inaccurate. The differences are, however, small in absolute value. The equations are valid, therefore, for use in predicting the scores at othersites

Table 9.3: Scores predicted from the regression equations and actual scores taken from the analysis in Chapter 6.

Allt Fuaran Diotach (6)			Feith Buidhe (17)		
	Predicted	Actual		Predicted	Actual
1	2.052	2.046	1	1.125	1.124
2	0.937	0.936	2	2.525	2.524
3	-0.777	-0.774	3	-0.866	-0.859
4	-0.195	-0.198	4	0.327	0.323
5	1.290	1.314	5	-0.566	-0.574
A. Coire an t-Sabhail (24)			A. Coire Chlachaich (42)		
	Predicted	Actual		Predicted	Actual
1	-2.723	-2.726	1	-0.588	-0.589
2	0.302	0.302	2	-0.563	-0.563
3	-0.747	-0.748	3	0.406	0.406
4	-0.071	-0.077	4	0.915	0.909
5	-1.194	-1.184	5	0.421	0.406

in the study area.

9.3 CASE STUDIES

Two case studies are described to outline the possible uses of the method. The first case study looks at six sites in the Cairn Gorm area, while the second case study looks at three sites at Drumochter where there are two different proposals for the development of facilities for downhill skiing.

9.3.1 Cairn Gorm

Facilities for downhill skiing were first developed at Coire Cas (site 15) in 1961 and later, in 1974, at Coire na Ciste (site 16). In 1980, the Cairngorm Chairlift Company put forward proposals to develop facilities for downhill skiing in Lurchers Gully (13), Coire an Lochain (14) and Coire an t-Sneachda. During a public inquiry into the proposals (held in 1981, see Scottish

Development Department, 1983), opponents to the scheme suggested that the snow-holding ability of Coire an Lochain and Coire an t-Sneachda was very poor, and put forward Coire Laogh Mor (see Location Map "A" in Appendix 1) as an alternative site for development.

The regression equations developed in section 9.2 can be used to predict the scores on the first five components for Coire an t-Sneachda and Coire Laogh Mor. Table 9.4 shows the scores predicted for both sites, together with those for the other sites at Cairn Gorm, and the summed totals (see also Table 8.3).

Table 9.4: Scores on the principal components for the Cairn Gorm sites

	1	2	3	4	5	Summed
Lurchers Gully	1.523	-0.349	-1.481	1.021	0.248	1.386
Coire an Lochain	-1.312	0.652	-2.135	1.081	1.231	-0.835
Coire an t-Sneachda	-0.824	-1.459	-1.702	0.806	1.376	-2.763
Coire Cas	-0.334	-1.681	-1.514	-0.120	1.635	-2.016
Coire na Ciste	1.029	-0.567	-0.901	-0.791	3.116	-0.962
Coire Laogh Mor	-0.414	0.311	-1.299	-0.628	-0.032	1.856

Coire Laogh Mor has the best summed score owing to a relatively good score on the fifth component. Lurchers Gully also has a good score owing to high values of gully side slope, snowdrift and wind-drift and a low value of global radiation. Of the six sites, Coire na Ciste is assumed often to be the best (Firsoff, 1965; Scottish Development Department, 1967; Watson, 1975). Although this is not confirmed by the summed score above, it is supported if the first four components only are summed. Lurchers Gully, Coire na Ciste and Coire Laogh Mor are then clearly the best sites. Coire an Lochain, Coire an t-Sneachda and

Coire Cas each have a poor combination of scores which suggests that they will have inconsistent snowcover relative to the three other sites. This is partly confirmed by the results from the measurement of the depth of snow in Coire an t-Sneachda, Coire an Lochain and Lurchers Gully in April, 1984 and April, 1985 (see Chapter 7). Depths of snow were very shallow in the gullies in Coire an Lochain and Coire an t-Sneachda, while a large, continuous, snowfield existed on the eastern slopes of Lurchers Gully and the snow was much deeper in the gully than at the two other sites.

It can be hypothesised that the site with the most consistent snowcover (i.e., those with the best combination of scores on the principal components) should have the greatest extent of snowpatch vegetation (see section 2.4.4). The extent of this vegetation was measured at the six sites for the public inquiry (Scottish Development Department, 1983, p.94). Table 9.5 shows these data and the summed scores over the first four and the first five components.

Table 9.5: Extent of snowpatch vegetation (ha.) and summedscores on the components

Site	1 - 4	1 - 5	Veg. (ha)
Lurchers Gully	1.634	1.386	13.50
Coire an Lochain	0.396	-0.835	2.38
Coire an t-Sneachda	-1.387	-2.763	2.12
Coire Cas	-0.381	-2.016	10.85
Coire na Ciste	2.154	-0.962	17.47
Coire Laogh Mor	1.824	1.856	10.35

There is a clear visual correlation between the summed total over the first four components and the extent of snowpatch vegetation at each site. Sites with the highest scores have the largest areas of snowpatch vegetation, while those with the lowest scores have the smallest areas. The data in Table 9.5 appears to support the suggestion made at the public inquiry (Scottish Development Department 1983, p.97) that "...while Lurchers Gully has good snow holding characteristics, Coire an t-Sneachda and Coire an Lochain are not nearly so suitable". Coire Cas has a relatively large area of snowpatch vegetation but a poor score. This vegetation is located on the steep headwall within that basin where snow is trapped and survives well into the summer (see Plate 4 in Chapter 6). Coire Laogh Mor has a high score owing to the relatively high values of top altitude, topographic rise and leeward slope. This site should, therefore, have more consistent snowcover than either Coire an Lochain or Coire an t-Sneachda.

In Chapter 7, it was concluded that both topographic rise and leeward slope had relatively strong positive correlations with the extent of snowcover. The results of this case study suggest that, for these six sites, the interpretation of the fifth component may not be valid. As the sites are all located on the very edge of the Cairngorms, it is possible that they may deviate from this trend.

The classification functions developed in Chapter 6 (see Table 6.9) can be used to allocate Coire an t-Sneachda and Coire Laogh Mor to their appropriate classes. The functions require data on top altitude, topographic rise, topographic exposure and wind-drift. Coire Laogh Mor is allocated to Class H and Coire an t-Sneachda to Class D (see section 6.3.2). It was noted in

Chapter 6 that sites in Class H have shallow and exposed basins with shallow gully side slopes. Coire Laogh Mor fits this description quite well owing to low values of gully side slope and basin ratio and a high value of topographic exposure. In Chapter 6, however, it was concluded that sites in Group H should have very limited snowfields and the least consistent snowcover of any group because of their relative inability to entrap snow and the low values of snowdrift and wind-drift. The relatively high values of topographic rise and leeward slope and low value of global radiation, however, suggest that this conclusion may not apply to Coire Laogh Mor. Class D, to which Coire an t-Sneachda was allocated, comprises the four other Cairn Gorm sites and site 53. The main characteristics of these sites are low values of topographic rise and leeward slope.

The results from the use of the regression equations and classification functions appear, in large part, to confirm the statements made at the public inquiry concerning the snow-holding characteristics of the six sites. The summed scores on the first four components appear to be quite strongly related to the extent of snowpatch vegetation at each site.

9.3.2 Drumochter

Although outwith the study area (see Chapter 1), the terrain at Drumochter is very similar in morphology to that in the SE Grampians, such that the Scottish Development Department (1967) and Bayfield et al. (1982) both considered Drumochter to be a part of the "Cairngorm Area". The results derived from this research can be applied, therefore, to sites at Drumochter.

Proposals to develop facilities for downhill skiing at two different sites at Drumochter have been put forward during the last three years. Figure 9.1 shows the two sites which are in Coire nan Cisteachan and Coire Uilleim to the north of the Pass

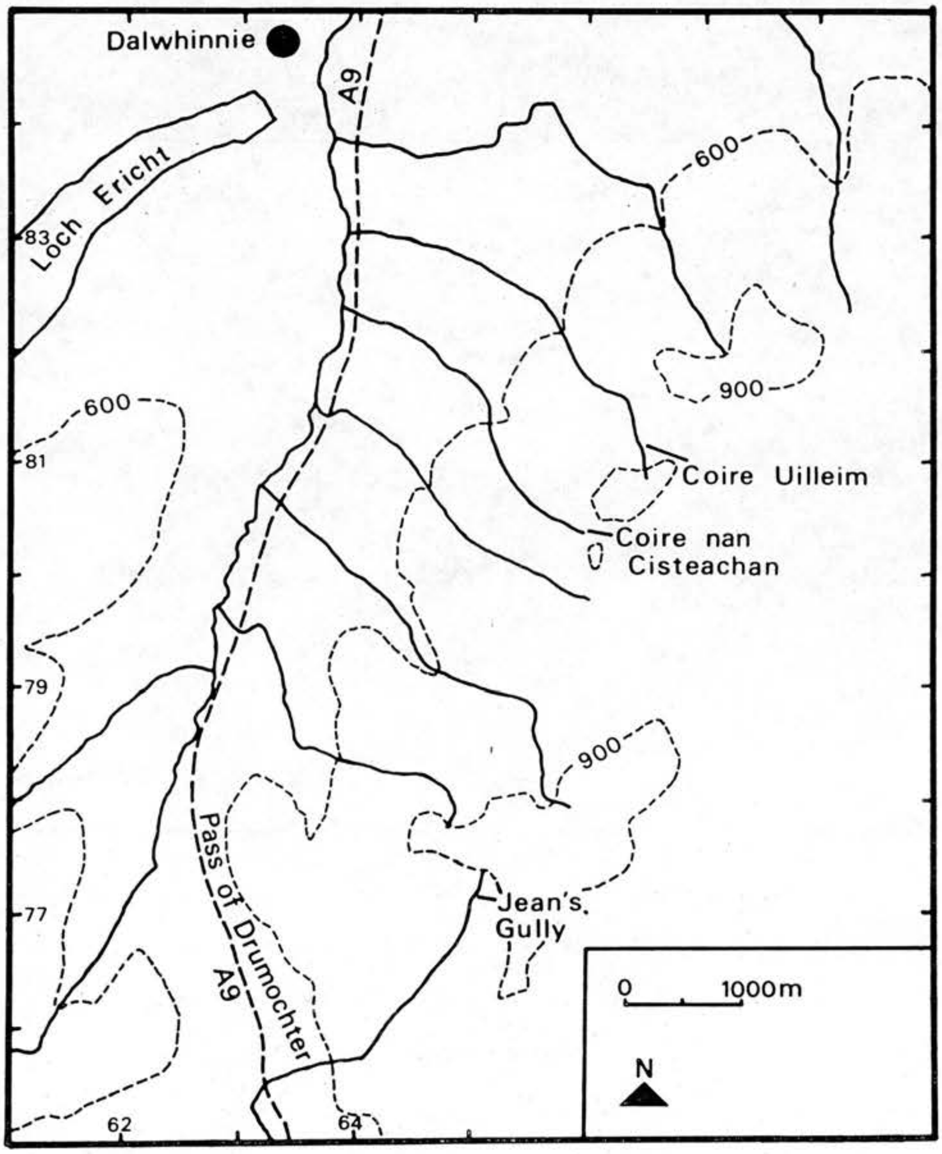


Figure 9.1: Location map of the Drumochter area.

of Drumochter (see Davison, 1982) and Jeans Gully to the south of the Pass. As it is unlikely that both proposals will be allowed to proceed, one of the problems facing planners and decision-makers is the need to compare the consistency of snowcover at the two sites. The regression equations and classification functions can be used to achieve this. Coire nan Cisteachan and Coire Uilleim will be regarded as two seperate sites. The data for the three sites are listed at the foot of Appendix 7.

Table 9.6 shows the predicted and summed scores on the first five principal components for the three sites. Allt Uilleim has a very high score on the first component owing to low values of topographic exposure and high values of gully side slope, fetch and wind-drift. Allt Uilleim should entrap more snow, therefore,

Table 9.6: Predicted and summed scores for three sites at Drumochter.

	1	2	3	4	5	Summed
A. Uilleim	3.188	-0.723	0.406	-1.693	1.488	2.264
A. Cisteachan	1.157	-1.503	-0.750	-1.496	1.673	0.227
Jeans Gully	1.814	-0.202	0.869	-0.602	1.661	-0.306

and receive greater amounts of wind-drift than the other two sites. All three sites have negative (i.e., poor) scores on the second component, owing to low values of top altitude and topographic rise. All have long fetch, however, which distinguishes them from those sites with the lowest scores on this component (see Tables 6.5 and 8.1). Jeans Gully has a poor score on the third component owing to a high value of global radiation and an average value of snowdrift. The site faces SSW and is leeward, therefore, to winds from the NE and NW only (and so receives only average snowdrift). Coire nan Cisteachan and Coire Uilleim face WNW and so receive much less global radiation. All three sites have good scores on the fourth component owing to high values of gully side slope and, for Coire nan Cisteachan and Coire Uilleim, low values of global radiation. All sites have poor scores on the fifth component owing to low values of topographic rise and leeward slope.

Coire Uilleim would appear, therefore, to have the best combination of scores on the first five components. The steep gully side slopes, low topographic exposure, long fetch and high value of wind-drift support this finding. The summed score is higher than those of the sites in the Cairn Gorm area (see Table 9.4) and is similar to those of sites in the Glen Feshie area (see Table 8.3). This finding confirms the suggestion made at the public inquiry (Scottish Development Department 1983, p.94) that "... that part of the Drumochter area has a far better natural snow holding capability than Coire an t-Sneachda and Coire an Lochain".

Coire nan Cisteachan and Jeans Gully both have low summed scores which are similar to those for a large number of sites, including Beanaidh Bheag (11), Allt Coire an t-Sabhail (24), Allt Coire Fionn (38), Allt an Tuirc (49) and Allt Coire Fhearneasg (54).

Using the classification functions (Table 6.9), Coire Uilleim and Coire nan Cisteachan are allocated to Class C and Jeans Gully to Class A. Sites in Class C have high values of gully side slope, fetch, snowdrift and wind-drift, but top altitude and topographic rise are below average. These two sites are similar, therefore, to sites 4,5,6,7,11,13,27 and 31, which with the exception of sites 27 and 31, are all located on the edge of the Cairngorms and so have low values of topographic rise and leeward slope. Sites in Class A have low values of top altitude, snowdrift, wind-drift and topographic exposure and high values of global radiation. This class comprises many sites from the SE Grampians and several from the Cairngorms.

Coire Uilleim is likely to have the most consistent snowcover of the three sites. The summed scores for Coire nan Cisteachan and Jeans Gully are very similar but for different reasons. The former has a relatively short fetch and low value of form ratio, while the latter has a long fetch but a high value of global radiation. Owing to the very low values of topographic exposure, the basin tends to be the dominant feature of Coire Uilleim and Jeans Gully, while the gully is the dominant feature at Coire nan Cisteachan owing to the low value of basin ratio.

9.3.3 Summary

The results of the two case studies show that the regression equations and classification functions can be used in applied studies to determine which sites should have the most consistent snowcover. Although the Cairn Gorm study was based only on six sites, the clear visual correlation between the summed scores on the first four components and the extent of snowpatch vegetation suggests that the results are valid measures of the consistency of snowcover and of natural potential.

The data used in this chapter and in Chapter 7 to validate and verify the method and the results have been very limited. Full validation and verification will require consistent and objective data on the extent and depth of snowcover at a large number of sites over a period of time (e.g., several winters) and on the extent of snowpatch vegetation at a larger number of sites than is available at present. The method can be regarded, therefore, as incomplete in that it expresses current knowledge based on the data wich are available. As more data are collected, modifications to the method and reinterpretation of the results will be required.

The comparison of the sites in the two case studies had only one aim, i.e., to identify which sites should have the most consistent snowcover. Observations of local snow and weather conditions are still required before any development is allowed to proceed. Before such data are collected, however, other factors need to be considered. These factors would include access to each site, the importance of each site to the conservation of nature and the sensitivity of the environment at each site to damage during and after development.

9.4 CONCLUSIONS

1. Regression equations can be used to predict the scores of any site on any component accurately and the classification functions derived from the discriminant analysis in Chapter 7 can be used to allocate new sites to their appropriate class. The method, therefore, can be applied by planners and decision-makers without the use of any computer.

2. The scores on the components appear to be strongly related to the extent of snowpatch vegetation at each site. This confirms the conclusions of Chapters 8 and 9, in that the scores do represent the natural potential of sites accurately.

3. The method, therefore, offers the opportunity for planners and

decision-makers to measure the natural potential of sites for downhill skiing accurately and in a manner which allows the results to be verified and justified.

CHAPTER 10: SUMMARY AND CONCLUSIONS

The main aim of this research was to measure the natural potential (defined as consistent snowcover during the winter) of sites for downhill skiing. This aim was to be achieved by fulfilling five objectives: to identify the processes that control the consistency of snowcover; to develop a method to measure the natural potential of sites for downhill skiing accurately; to validate the results using data on the consistency of snowcover; to improve knowledge of the processes that control the consistency of snowcover; and to suggest ways of refining the method. A particular need was for the method to measure potential accurately, so emphasis was placed on identifying the processes that control the consistency of snowcover and on validating and verifying the results.

The absence of data on snowcover dictated that the method be based on the morphology of the land surface and its influence on the supply, entrapment and retention of snow. Five processes that control the consistency of snowcover were identified: the creation of turbulence in the air; gradients of precipitation and temperature; the relative supply of snow; global radiation; and the upwind depletion of precipitation. Eleven variables that could be measured from Ordnance Survey maps, were identified to represent these processes. The weather of thirty winters over the period 1954/5 to 1983/4 was studied to provide data on the relative supply of snow to each site. This database is verifiable and can be enlarged and analysed continuously. Results from the interpretation of the database challenge many beliefs on weather patterns during winter in the Scottish Highlands long-held by those involved in downhill skiing.

It was argued that potential is a relative, rather than absolute, phenomenon and that it can be measured accurately only with reference to a large number of sites. A value of potential for a single site is meaningless unless that value can be compared against other values or against a standard which represents potential. The method had to determine if one site had more consistent snowcover than another, and develop a standard by which the potential of other sites could be compared.

It was hypothesised that those sites with the best combination of values on the variables chosen to represent these processes would have the most consistent snowcover. This was equivalent to assessing the null hypothesis that each variable had an independent spatial distribution. Principal components analysis, cluster analysis and discriminant analysis were used to achieve this and represent the method.

Although the loadings of the variables on the components were relatively low (the relationships between the variables are not causal), their relationship to the consistency of snowcover was quite clear. The components were interpreted as combinations of inter-related variables which reflected the consistency of snowcover at the sites. Each site has a score on each component that reflects the loadings of the variables and the values of each site on each variable. The scores can be used, therefore, as measures of the potential of each site. To validate this, the scores were used in regression analyses with a dependent variable - the extent of snowcover in each gully - chosen to represent the consistency of snowcover. The results were encouraging and were particularly good for those dates on which the melt season was well advanced, i.e., when only deep snow remains. A small case study showed that the summed scores were closely correlated with the extent of snowpatch vegetation at each sites. The accuracy of the method, however, could be improved in several ways and these are suggested later in this chapter.

The method can be used to identify groups of sites with similar characteristics, and so similar potential, and to determine if the differences between the groups are statistically significant. The classification is more refined, therefore, than that of the Canada Land Inventory, for example, where the classes are defined subjectively and not tested for validity. Discriminant functions can be used to allocate new sites to their appropriate class.

The thesis introduced two additional aids to the interpretation of the results:

1. converting the scores to represent their relationship to potential (e.g., a high negative score may represent high potential) and them summing them, and
2. regression equations for predicting the relevant scores for sites not used in the analysis.

The former allows those sites with the best combination of scores to be identified and for all sites to be ranked according to the consistency of snowcover at each. The list of summed scores represent a standard of potential from the site with the highest score (i.e., most consistent snowcover) to the one with the lowest score (i.e., least consistent snowcover). The latter (2) can be used by planners and decision-makers to predict the scores for any site (s) within the study area that they are interested in. The result can be compared with the standard of potential offered by the summed scores for the original sample of sites.

The most important processes that control the consistency of snowcover appear to be gradients of precipitation and temperature, the upwind depletion of precipitation and, to a lesser extent, the creation of turbulence in the air. These results correspond well with those of studies in the European Alps and in North America. The amount of precipitation, therefore, appears to be an important factor in determining the natural potential of sites for downhill skiing. As the data available on actual amounts of precipitation are limited, future research should concentrate on this problem. Given adequate data, it should be possible to predict approximate amounts of precipitation over the study area, as has been done by researchers for the Rocky Mountains in Colorado.

The research found that many sites have snowcover that is more consistent than at the sites which have been developed to date and that all sites suffer from at least one poor value on a variable or a poor component score. This finding suggests that the initial decision to concentrate on the consistency of snowcover was a wise one. Any investigation into the potential of sites for downhill skiing should bear these findings in mind. The Government, through the Scottish Development Department, should revise the National Planning Guidelines accordingly and encourage the study of a wider number of sites than is covered presently within that document. It should be noted, however, that the method is concerned only with the consistency of snowcover and not with questions of access, nature conservation or suitability of slopes. It is hoped that research is undertaken on methods for "screening" the sites for access and impact on the conservation of nature.

The method, and the philosophy behind it, could be developed and tested further in seven ways. These are discussed in turn.

1. The location of late-lying and semi-permanent snowpatches could be examined, as they should have very good supply, entrapment and retention characteristics. The sites occupied by these snowpatches should have the highest summed scores on the components or should comprise a single class in a classification of many sites. The main problem would be that of sampling: sites with semi-permanent snowpatches and those without would need to be studied to avoid the work being biased towards the former.

2. Given adequate time and resources, the actual amount of precipitation could be measured and modelled, as this influences the extent of snowcover (i.e., the dependent variable) strongly at each site. Snow shadows produced as storms travel across massifs are of particular importance, as they account for a large proportion of total snowdrift. This process (an extension of the upwind depletion of precipitation) could be studied further by using NOAA satellite imagery which, although having a spatial resolution of one kilometre, covers the country each day. Use could be made of the classification of the topography and vegetation of the Eastern Highlands of Scotland by Bayfield et al. (1982), which was undertaken at a scale of one kilometre

(grid squares on Ordnance Survey maps) and corresponds with the resolution of the NOAA imagery. The results of such research should help to establish the frequency and spatial extent of snow shadows.

Effort in the short-term could be concentrated on a more detailed analysis of snowstorms, which were shown to account for at least 29.5% of total snowdrift on only 3.15% of all days. Snowdrift and, in particular, snowstorms could be measured more accurately by calculating the gradient wind force and developing classes to represent the exponential relationship between wind speed and the drifting of snow.

3. The influence of the topography and vegetation within a basin on the pattern of snowcover could be studied. The detailed observation of snowcover within several basins may help to identify variables to represent these factors. A preliminary study might examine data measured at each transect along a gully.

4. The collection of data on wind speed and direction at individual sites. The use of a single wind direction for all sites within the study area is a serious constraint upon the calculation of snowdrift and wind-drift.

5. The dependent variable could be defined to represent the amount of snow at each site more accurately, for this influences the validity of the results. This would involve the collection of more data on the depth of snow at a larger number of sites than was achieved in this research. The use of photogrammetric techniques and the commissioning of aerial photographs with this specific purpose in mind would be necessary.

6. The method, and the philosophy that the site with the highest potential will have the best combination of values on the variables measured, could be applied to different land uses or to a wider definition of potential. Potential would have to be redefined and the processes that control the level of potential identified. A dependent variables to represent the definition of potential would also be required. A single variable, however, is unlikely to be identified for a definition of potential wider than that used in this thesis (e.g., consistency of snowcover and access would probably require two variables).

7. The method could be applied to a sample of existing ski areas in Switzerland (or any other country where the size of the sample would be large) and the results validated against what data are available. This work may help to identify a dependent variable which is more suitable for a wider definition of potential. Without such a variable, researchers may have to investigate the components of potential (e.g., physical or economic or social, etc.) separately, for which dependent variables may be identified more easily, and then develop a way of combining the results.

The method is valid in its present form, however, although it could and should be refined and tested further. It can be used by planners and decision-makers, provided they are aware of its limitations and verified the results against data collected from other sources.

The thesis has two main conclusions. First, principal components analysis and other multivariate techniques do offer the opportunity to measure the potential of land for downhill skiing accurately by identifying those sites with the best combination of values on the variables measured. The scores on the components are measures of potential that can be easily validated using regression analyses, provided a dependent variable can be identified to represent potential. The results can be justified by referring back to the original data, which can be achieved rarely with other methods.

The second conclusion is that when the measurement of potential is based on known relationships, on explicit and tested assumptions and on its multivariate nature, the results often challenge the long-held beliefs of people who have based their work on assumptions which are implicit and untested and on imperfect knowledge. The results and the study of winter weather are ample proof of this. Any attempts to measure potential in future should base their work on explicit and, where possible, tested assumptions, on a thorough review of the processes involved and on a validation of results against a dependent variable chosen to represent potential.

The research must be viewed as a first attempt to examine snowcover in the Scottish Highlands in detail and with due recognition to the paucity of data on snow and weather conditions in that area. Attempts have been made to investigate the processes involved, to identify sites with the most consistent snowcover and to establish a long-term database on winter weather with considerable success. The method is based on current knowledge, however, and both it and the interpretation of results can be improved as further knowledge becomes available.

BIBLIOGRAPHY

ALFORD, D. L. (1973) Cirque glaciers of the Colorado Front Range: meso-scale aspects of a glacier environment. PhD thesis, University of Colorado: Boulder.

ANDERSON, H. W. and PAGENHART, T. H. (1957) Snow on forest slopes. In Western Snow Conference, 25th meeting, pp.19-23. Colorado Springs.

ANDERSON, H. W. and WEST, A. J. (1965) Snow accumulation and melt in relation to terrain in wet and dry years. In Western Snow Conference, 33rd. meeting, pp. 73-82. Colorado Springs.

ANDERSON, R. F. and GREENBERG, M. R. (1982) Hazardous waste facility siting: a role for planners. Journal of the American Planning Association, 48, 204-218.

BAGNOLD, R. A. (1941) Physics of blown sand and desert dunes. Methuen: London.

BAKER, M. J. and GORDON, A. W. (1975) Aonach Mor: a feasibility report. Scottish Tourist Board: Edinburgh.

BAKER, M. J. and GORDON, A. W. (1980) Winter sports development study - Phase 3. Scottish Tourist Board: Edinburgh.

BALLANTYNE, C. K. (1981) Periglacial landforms and environments on mountains in the Northern Highlands of Scotland. PhD thesis. University of Edinburgh: Edinburgh.

BALLANTYNE, C. K. (1983) Precipitation gradients in Wester Ross, North-West Scotland. Weather, 38, 379-387.

BALLANTYNE, C. K. (1985) Nivation landforms and snowpatch erosion on two massifs in the Northern Highlands of Scotland. Scottish Geographical Magazine, 101, 40-49.

BARRY, R. G. (1981) Mountain weather and climate. Methuen: London.

BARTON, J. S. (1984) Observing mountain weather using an automatic station. Weather, 39, 140-145.

BAYFIELD, N. G., PENNY, M. G. and MOYES, S. M. (1982) An indicator species analysis of map squares and vegetation in the Cairngorms. Transactions of the Botanical Society of Edinburgh, 44, 35-47.

BERG, N. H. (1977) Prediction of snowdrift accumulation at alpine sites. PhD thesis. University of Colorado: Boulder.

BORTHWICK, A. S. (1983) Mountain weather in Scotland. Processing and preliminary analysis of data from an automatic weather station on Cairn Gorm. M.Phil. thesis. University of Edinburgh.

BOVIS, M. J. (1976) Statistical analysis. In Armstrong, R. L. and Ives, J. D. (Eds.) Avalanche release and snow characteristics, San Juan Mountains, Colorado, pp. 83-130. Occ. Paper 19, Institute for Arctic and Alpine Research: Boulder.

BRIDEL, L. (1970) Les champs de ski du Canton de Vaud. Cahier No. 10. Office Cantonal Vaudois de l'Urbanisme: Lausanne.

BUDD, W. F., DINGLE, W. R. J. and RADOK, U. (1966) The Byrd Snow Drift Project: outline and basic results. In Studies in Antarctic Meteorology, Antarctic Research Series Vol. 9, pp. 71-134. American Geophysical Union.

BUTLER, R. W. (1967) Report on a survey of potential development of Beinn a' Bhuird. Scottish Tourist Board: Edinburgh.

CAINE, N. (1975) An elevational control of peak snowpack variability. Water Resources Bulletin, 11, 613-621.

CANADA LAND INVENTORY (1969) Land capability classification for outdoor recreation. Report No. 6. Dept. of Regional Economic Expansion: Ottawa.

CHAMPION, D. L. (1950) Ablation in the Scottish Highlands. Meteorological Magazine, 79, 292-295.

CLYDE, R. M. (1981) Precognition on behalf of the Cairngorm Chairlift Company to the public inquiry into proposals for development of Lurchers Gully. Cairngorm Chairlift Company: Aviemore.

COLWELL, R. N. (1983) (Ed.) Manual of remote sensing. 2nd. edition. American Society of Photogrammetry: Falls Church, Virginia.

COOKE, R. U. and DOORNKAMP, J. C. (1974) Geomorphology in environmental management. An introduction. Clarendon Press: Oxford.

COOPER, R. A. and WEEKES, A. J. (1983) Data, models and statistical analysis. Philip Allan: Oxford.

CROWE, R. B., McKAY, G. A. and BAKER, W. M. (1978) The tourist and outdoor recreation climate of Ontario. Volume 3: The winter season. Report REC-1-73. Atmospheric Environment Service: Ottawa.

DALY, C. (1984) Snow distribution patterns in the alpine krummholz zone. Progress in Physical Geography, 8, 157-175.

DAVIDSON,D.A.(1980) Soils and land use planning. Topics in Applied Geography. Longman: London.

DAVIS, J. C. (1973) Statistics and data analysis in geology. John Wiley: New York.

DAVISON, R. W. (1981) Ski developments in Scotland - what lies ahead? Scottish Geographical Magazine, 97, 110-123.

DAVISON, R. W. (1982a) Planning and downhill skiing development. BSc. dissertation. University of Dundee: Dundee.

DAVISON,R.W.(1982b) Environmental report on downhill ski development proposals for Coire nan Cisteachan and Coire Uilliem at Drumochter. Drumochter Ski Development Group: Newtonmore.

DAVISON, R. W. (1985) The measurement of site potential for downhill skiing. In Bayfield, N. G. and Barrow, G. C. (Eds.) The ecological impacts of outdoor recreation on mountain areas in Europe and North America, pp. 188-197. Recreation Ecology Research Group report No. 9. University of Aberdeen Press.

DENT, D. and YOUNG, A. (1981) Soil survey and land evaluation. George Allen and Unwin: London.

DIXON, W. J. and BROWN, M. B. (1977) BMDP-77. Biomedical computer programs: P-series. University of California Press: Berkeley.

DOWDESWELL, J. A. (1982) Relative dating of Late Quaternary deposits using cluster and discriminant analysis, Audubon Cirque, Mt. Audubon, Colorado Front Range. Boreas, 11, 151-161.

DOZIER, J. and OUTCALT, S. I. (1979) An approach toward energy balance simulation over rugged terrain. Geographical Analysis, 11, 65-85.

DUFFIELD, B. S. and OWEN, M. L. (1970) Leisure + Countryside =, a geographical appraisal of countryside recreation in Lanarkshire. Tourism and Recreation Research Unit: University of Edinburgh.

DYBECK, M. W. and GREEN, F. H. W. (1955) The Cairngorms Weather Survey, 1953. Weather, 10, 41-48.

DYUNIN, A. K., ANFILOFIYEV, B. A., ISTRAPILOVICH, M. G., KVON, Ya. D. and MAMAYEVA, N. T. (1977) Strong snow-storms, their effect on snow cover and snow accumulation. Journal of

Glaciology, 19, 441-449.

DYUNIN, A. K. and KOTLYAKOV, V. M. (1980) Redistribution of snow in the mountains. Cold Regions Science and Technology, 3, 287-294.

EIDGENOSSICHE INSTITUT FÜR SCHNEE- UND LAWINENFORSCHUNG (1982) Schnee und Lawinen in den Schweizer Alpen Winter 1980/81. Number 45. EISLF: Weissfluhjoch, Davos.

ELSASSER, B., FEHR, U. and MAURHOFER, F. (1977) Erholungsraume im Berggebiet. Elecktrowatt Ingenierungternehmung AG: Bern.

FARNES, P. E. (1971) Snowfall at potential ski areas from snow survey data. In Haugen, A. O. (Ed.) Proceedings of the Snow and Ice in relation to Wildlife Symposium, February 11-12, 1971. Iowa State University: Ames. (pp.184-192).

FERGUSON, R. I. (1984) Magnitude and modelling of snowmelt runoff in the Cairngorm Mountains, Scotland. Hydrological Sciences Journal, 29, 49-62.

FIRSOFF, V. A. (1965) On ski in the Cairngorms. W. and R. Chambers: Edinburgh.

FÖHN, P. M. B. (1980) Snow transport over mountain crests. Journal of Glaciology, 26, 469-480.

FÖHN, P. M. B. and MEISTER, R. (1983) Distribution of snow drifts on ridge slopes: measurements and theoretical approximations. Annals of Glaciology, 4, 52-57.

FRENKEL, R.E. and HARRISON, C. M. (1974) An assessment of the usefulness of phytosociological and numerical classificatory methods for the community biogeographer. Journal of Biogeography, 1, 27-56.

GETZ, D. (1980) The impact of tourism on host populations in the Spey Valley. PhD thesis. University of Edinburgh: Edinburgh.

GLIDDEN, D. E. (1982) Winter wind studies in Rocky Mountain National Park. Rocky Mountain Nature Association: Colorado.

GLOYNE, R. W. (1968) Some climatic influences affecting hill land productivity. In Hunt, I. V. (Ed.) Hill Land Productivity, pp. 9-15. British Grassland Society, Symposium No. 4. Aberdeen, 1968.

GOELDNER, C. R. and FARWELL, T. (1980) Economic analysis of North American ski areas. Business research Division. University of Colorado: Boulder.

GOODISON, B. E., FERGUSON, H. L. and McKAY, G. A. (1981) Measurement and data analysis. In Gray, D. M. and Male, D. H. (Eds.) Handbook of Snow. Principles, processes, management and use, pp. 191-274. Pergamon Press: Toronto.

GRANBERG, H. B. (1978) Snow accumulation and roughness changes through winter at a forest-tundra site near Schefferville, Quebec. In Colbeck, S. C. and Ray, M. (Eds.) Modelling of snow cover runoff, pp. 83-92. US Army Cold Regions Research and engineering Laboratory: Hanover, New Hampshire.

GREEN, F. H. W. (1967) Air humidity on Ben Nevis. Weather, 22, 174-184.

GREEN, F. H. W. (1968) Persistent snowbeds in the Western Cairngorms. Weather, 23, 206-209.

GREEN, F. H. W. (1973) Changing incidence of snow in the Scottish Highlands. Weather, 28, 386-394.

GREGORY, K. J. and WALLING, D. E. (1973) Drainage basin form and process. A geomorphological approach. Edward Arnold: London.

HENDRICK, R. L., FILGATE, B. D. and ADAMS, W. M. (1971) Application of environmental analysis to watershed snowmelt. Journal of Applied Meteorology, 10, 418-429.

HERIOT-WATT UNIVERSITY (1983) Cairngorm mountain weather project. Department of Physics, Heriot-Watt University: Edinburgh.

HIGHLAND REGIONAL COUNCIL (1977) Regional report: Settlement Policy No.3. Major tourism/recreation projects - winter sports. Highland Regional Council: Inverness.

HIGHLAND REGIONAL COUNCIL (1980) Summary report of the Winter Sports Technical Working Party. Highland Regional Council: Inverness.

HOLROYD, E. W., III (1970) Prevailing winds on Whiteface Mountain as indicated by flag trees. Forest Science, 16, 222-229.

HOPE, K. (1968) Methods of multivariate analysis. University of London Press: London.

HUDSON, I. C. (1976) Cairngorm snow-field report 1975. Journal of Meteorology, 1, 284-286.

HÜNERWADEL, D., RUDIN, R., RÜSCH, W., SCHWARZENBACH, F. H., STIFFLER, H.-K., WÄLLIMANN, B. and WEISS, H. (1982) Skipistenplanierungen und Gelandekorrekturen-Erfahrungen und Empfehlungen. Berichte No. 237. Eidg. Anstalt für das Forstliche Versuchswesen, Birmensdorf, CH.

HUNTER, J. A. K. (1964) Access to snow holding mountains in Britain. In Nature Conservancy (Ed.) The countryside in 1970, pp. 219-222. Nature Conservancy: HMSO.

ISARD, S. A. (1983) Estimating potential direct insolation to alpine terrain. Arctic and Alpine Research, 15, 77-89.

IVES, J. D. and FAHEY, B. D. (1971) Permafrost occurrence in the Front Range, Colorado Rocky Mountains, U.S.A.. Journal of Glaciology, 10, 105-111.

JACKSON, M. C. (1977) A classification of the snowiness of 100 winters - a tribute to the late L.C.W. Bonacina. Weather, 32, 91-97.

JACKSON, M. C. (1978) Snow cover in Great Britain. Weather, 33, 298-309.

JOHNSTON, R. J. (1980) Multivariate statistical analysis in geography. Longman: London.

JUBENVILLE, A. (1976) Outdoor recreation planning. W.B. Saunders: New York.

KENNEDY, B. A. (1976) Valley-side slopes and climate. In Derbyshire, E. (Ed.) Geomorphology and climate, pp. 171-202. John Wiley: London.

KING, L. J. (1969) Statistical analysis in geography. Prentice-Hall: Englewood Cliffs, New Jersey.

KING, R. B. (1968) Periglacial features of the Cairngorm Mountains. PhD thesis. University of Edinburgh.

KOTLYAKOV, V. M. and PLAM, M. Y. (1966) The influence of drifting on snow distribution in the mountains and its role in the formation of avalanches. In International Symposium on Scientific Aspects of Snow and Ice Avalanches, 5-10 April, 1965, Davos, pp. 53-60. IASH Publication 69, Paris.

KRIPPENDORF, J. and ANNASOHN, K. (1976) Grundlagen zu den Leitlinien für die Berggebietsforderung. Erganzungen 2. Zentralstelle für regionale Wirtschaftsforderung: Bern.

KUZ'MIN, P. P. (1963) Snow cover and snow reserves. National Science Foundation: Washington, D.C..

LAMB, H. H. (1972) British Isles weather types and a register of the daily sequence of circulation patterns 1861-1971. Geophysical Memoir 116. Meteorological Office: Bracknell.

LANGMUIR, E. (1970) Snow profiles in Scotland. Weather, 25, 205-209.

LANGMUIR SKI GROUP (1979) Snow condition and topographical survey. Winter Sports Technical Working Party. Highland Regional Council: Inverness.

LEUSCHNER, W. A. (1970) Skiing in the Great Lakes States: the industry and the skier. Research Paper NC-46. North Central Forest Experiment Station. United States Forest Service: St. Paul.

LOEWE, F. (1972) The land of storms. Weather, 27, 110-122.

LOWNDES, C. A. S. (1971) Substantial snowfalls over the United Kingdom, 1954-69. Meteorological Magazine, 100, 193-207.

McINTOSH, D. H. and THOM, A. S. (1981) Essentials of meteorology. The Wykeham Science Series 3. Taylor and Francis: London.

McKAY, G. A. (1970) Problems of measuring and evaluating snow-cover. In Proceedings of CNC/IHD Workshop Seminar on Snow Hydrology, February 28-29, 1968, University of New Brunswick, pp.48-62. Canadian National Committee for the International Hydrological Decade: Ottawa.

McKAY, G. A. and GRAY, D. M. (1981) The distribution of snow-cover. In Gray, D. M. and Male, D. H. (Eds.) Handbook of snow. Principles, processes, management and use, pp. 153-190. Pergamon Press: Toronto.

MANLEY, G. (1969) Snowfall in Britain over the past 300 years. Weather, 24, 428-437.

MANLEY, G. (1971) The mountain snows of Britain. Weather, 26, 192-201.

McPARTLAND, J. T., SUPER, A. B. and MITCHELL, V. L. (1971) Snow-pack accumulation in relation to terrain and meteorological factors in SW Montana. Report of the Montana State University: Bozeman.

MARRIOTT, F. H. C. (1974) The interpretation of multiple observations. Academic Press: London.

MARTINELLI, M., Jr. (1965) Accumulation of snow in alpine areas of central Colorado and means of influencing it. Journal of Glaciology, 5 (41), 625-636.

MARTINELLI, M., Jr. (1975) Water-yield improvement from alpine areas: the status of our knowledge. Research Paper RM-138. Rocky Mountain Forest Experiment Station, United States Forest Service: Fort Collins.

MARTINELLI, M., Jr. (1976) Meteorology and ski area development and operation. In Proceedings of the 4th National Conference on Fire and Forest Meteorology, pp. 75-82. General Technical Report RM-32. Rocky Mountain Forest Experiment Station, United States Forest Service: Fort Collins.

MATHER, P. M. (1976) Computational methods of multivariate analysis in physical geography. John Wiley: London.

MATHER, P. M. and DOORNKAMP, J. C. (1970) Multivariate analysis in geography with particular reference to drainage basin morphology. Transactions of the Institute of British Geographers, 51, 163-187.

McVEAN, D. N. (1958) Snow cover and vegetation in the Scottish Highlands. Weather, 13, 197-200.

McVEAN, D. N. (1963) Snowcover in the Cairngorms 1961-62. Weather, 18, 339-342.

McVEAN, D. N. and LOCKIE, J. D. (1969) Ecology and land use in upland Scotland. Edinburgh University Press: Edinburgh.

McVEAN, D. N. and RATCLIFFE, D. A. (1962) Plant communities of the Scottish Highlands. Monograph No. 1. Nature Conservancy: HMSO.

MEIMAN, J. R. (1970) Snow accumulation related to elevation, aspect and forest canopy. In Proceedings of the CNC/IHD Workshop Seminar on Snow Hydrology, February 28-29, 1968, University of New Brunswick, pp. 35-47. Canadian National Committee for the International Hydrological Decade: Ottawa.

MEIMAN, J. R., REMMENGA, E. and KELLER, H. (1971) Snow distribution in relation to solar radiation on two Swiss Pre-Alp watersheds. Water Resources Research, 7, 1636-1640.

MEISTER, R. (1983) Ermittlung der Schneehohenverteilung mit Hilfe der Photogrammetrie. In Eidgenossiche Institutes fur Schnee- und Lawinenforschung (Ed.) Winterbericht Nr. 46, pp. 135-139. EISLF: Weissfluhjoch, Davos.

MELLOR, M. (1965) Blowing snow. Part III, Section A3C. Cold Regions Science and Engineering Laboratory: Hanover.

MESSERLI, P. (1983) The concept of stability and instability of mountain ecosystems derived from the Swiss MAB-6 studies of the Aletsch area. Mountain Research and Development, 3, 281-290.

METEOROLOGICAL OFFICE (1962) Observer's Handbook. 2nd. Edition. Meteorological Office: HMSO.

MICHNA, E. and PACZOS, S. (1976) Climatological criteria for evaluation of snow conditions required for recreation and winter sports by example of SE Poland. In Gerasimov, I. P. (Ed.) XXIII International Geographical Congress, Section 2, pp. 72-76. Moscow.

MILLER, W. F. and CARTER, B. D. (1979) Rational land use decision making: the Natchez State Park. Remote Sensing of Environment, 8, 25-38.

MINNICH, R. A. (1984) Snow drifting and timberline dynamics on Mount San Gorgonio, California, U.S.A.. Arctic and Alpine Research, 16, 395-412.

MOORE, R. D. and OWENS, I. F. (1984) Controls on advective snowmelt in a maritime alpine basin. Journal of Climate and Applied Meteorology, 23, 135-144.

MORGAN, R. P. C. (1976) The role of climate in the denudation system: a case study from West Malaysia. In Derbyshire, E. (Ed.) Geomorphology and climate, pp. 317-342. John wiley: London.

MORRIS, E. M. (1982) Sensitivity of the European Hydrological System snow models. In Hydrological Aspects of Alpine and High-Mountain Areas, Proceedings of the Exeter Symposium, July 1982, pp. 221-231. Publication No. 138. IAHS: Paris.

MORRIS, E. M. (1983) Modelling the flow of mass and energy within a snowpack for hydrological forecasting. Annals of Glaciology, 4, 198-203.

NAGELI, W. (1971) Der Wind als Standortsfaktor bei Aufforstungen in der subalpinen Stufe (Stillbergalp im Dischmatal, Kanton Graubunden). Mitteilungen, 47, 35-147. Eidgenossiche Anstalt fur Forstwesen Versuchswesen: Birmensdorf.

NATURAL ENVIRONMENT RESEARCH COUNCIL (1975) Flood Studies Report, Volume 2. Natural Environment Research Council: Swindon.

NELSON, C. E. (1971) Southwest Montana ski area resources, development and use patterns. PhD thesis. University of Nebraska: Lincoln.

NIE, N. H., HULL, C. H., JENKINS, J. G., STEINBRENNER, K., BENT, D. M. (1975) Statistical package for the social sciences. 2nd. Edition. McGraw-Hill: New York.

NORTH EAST MOUNTAIN TRUST (1983) Policy on downhill skiing developments in Scotland. North East Mountain Trust: Aberdeen.

NORTHERN SPORTS COUNCIL (1973) Skiing in the North. Northern Sports Council: Newcastle.

OBLED, C. and GOOD, W. (1980) Recent developments of avalanche forecasting by discriminant analysis techniques: a methodological review and some applications to the Parsenn area (Davos, Siwtzerland). Journal of Glaciology, 25 (92), 315-345.

OBLED, C. and HARDER, H. (1978) A review of snowmelt in the mountain environment. In Colbeck, S. C. and Ray, M. (Eds.) Modelling of snowcover runoff, pp. 179-203. Cold Regions Research and Engineering Laboratory: Hanover.

OWENS, I. F. and PROWSE, T. D. (1979) Meteorological information in ski-field planning. In Proceedings of Symposium on Meteorology and Planning, October 1979, pp. 163-184. New Zealand Meteorological Service: Wellington.

PARNELL, B. K. (1974) Aonach Mor. A planning report on the prosepct of winter sport development at Fort William. Scottish Tourist Board: Edinburgh.

PEARS, N. V. (1964) The present tree-line in the Cairngorm Mountains of Scotland and its relation to former tree-lines. PhD thesis. University of London: London.

PEDGLEY, D. E. (1970) Heavy rainfalls over Snowdonia. Weather, 25, 340-350.

PEDGLEY, D. E. (1971) Some weather patterns in Snowdonia. Weather, 26, 412-444.

PERRY, A. (1971) Climatic influences on the Scottish skiing industry. Weather, 87, 197-201.

PRICE, H. A. (1970) The ski resort and its feasibility. Journal of Travel Research, 2, 1-4.

PROWSE, T. D. (1981) The snow environment of the Craigieburn Range. PhD thesis. University of Canterbury: Christchurch.

PROWSE, T. D. and OWENS, I. F. (1982) Energy balance over melting snow, Craigieburn Range, New Zealand. Journal of Hydrology (New Zealand), 21, 133-146.

RADOK, U. (1970) Boundary processes of drifting snow. Publication No. 13, pp. 1-41. Department of Meteorology, University of Melbourne: Melbourne.

RADOK, U. (1977) Snow drift. Journal of Glaciology, 19 (81), 123-139.

RAWLS, W. J. and JACKSON, T. J. (1979) Pattern recognition analysis of snowdrifts. Nordic Hydrology, 10, 251-260.

RHEA, J. O. (1977) Orographic precipitation model for hydrometeorological use. PhD thesis. Colorado State University: Fort Collins.

RHEA, J. O. and GRANT, L. O. (1975) Topographic influences on snowfall patterns in mountainous terrain. In Advanced Concepts and Techniques in the Study of Snow and Ice Resources, pp. 182-192. National Academy of Science: Washington D.C..

RICHARDS, K. (1982) Rivers. Form and process in alluvial channels. Methuen: London.

SANDOR, P. E. (1980) Policy implications of better utilising ski areas in the Canadian Rocky Mountains. In Hawkins, D. E., Shafer, E. L. and Ravelstad, J. M. (Eds.) Tourism planning and development issues, pp. 333-344. Pergamon Press: Toronto.

SANDSBORG, J. (1970) The effect of wind on the precipitation distribution over a hillock. Nordic Hydrology, 4, 235-244.

SCHAER, U. (1976) Grundlagen fur die wirtschaftliche Beurteilung von Seilbahnen - Eine kritische Analyse Schweizerischer Verhaltnisse. Heft 18. Berner Studien zum Fremdenverkehr im Verlag Lang and Cie AG: Bern.

SCHMID, P. and KELLER, P. (1977) Konzessionskonzept. Prufungsgrundlagen fur Konzessionsgesuche. Fremdenverkehrsdienst, Eidgenossiche Amtes fur Verkehr: Bern.

SCOTTISH DEVELOPMENT DEPARTMENT (1967) Cairngorm Area. Report of the Technical Group on the Cairngorm Area of the Eastern Highlands of Scotland. Scottish Development Department: HMSO.

SCOTTISH DEVELOPMENT DEPARTMENT (1983) Report of the public inquiry into proposals to develop facilities for downhill skiing at Lurchers Gully, Cairn Gorm. Scottish Development Department: HMSO.

SCOTTISH DEVELOPMENT DEPARTMENT (1984) National Planning Guidelines: Skiing Developments. Scottish Development Department: HMSO.

SELIGMAN, G. (1936) Snow structure and ski fields. Macmillan: London.

SIMPSON, M. (1982) "Skisters". The story of Scottish skiing. Landmark Press: Carrbridge.

SISSONS, J. B. (1979) The Loch Lomond Advance in the Cairngorm Mountains. Scottish Geographical Magazine, 95, 66-82.

SISSONS, J. B. (1980) Palaeoclimatic inferences from Loch Lomond Advance glaciers. In Lowe, J. J., Gray, J. M. and Robinson, J. E. (Eds.) Studies in the Lateglacial of North-West Europe, pp. 31-43. Pergamon Press: Oxford.

SISSONS, J. B. and SUTHERLAND, D. G. (1976) Climatic inferences from former glaciers in the South-East Grampian Highlands, Scotland. Journal of Glaciology, 17 (76), 325-346.

SLESSER, M. (1970) Scottish mountains on ski. West Col Productions: Reading.

SMITH, K. (1975) Some comments on the climatological aspects of a planning report on the prospects for winter sports development on Aonach Mor. In Baker, M. J. and Gordon, A. W. (Eds.) Aonach Mor: a feasibility report, Appendix A. Scottish Tourist Board: Edinburgh.

SMITH, K. E. (1974) Location analysis of high-volume skiing in Western United States. PhD thesis. University of Minnesota: Milwaukee.

SNO-ENGINEERING (1981) Denali State Park - Tokositna site. Skiing and outdoor recreation feasibility analysis. Executive Summary Report. Sno-Engineering: Lyme, New Hampshire.

SPINK, P. C. (1980) Summary of summer snow surveys in Scotland: 1965-1978. Journal of Meteorology, 5 (48), 105-111.

SPREEN, W. C. (1947) Determination of the effect of topography on precipitation. Transactions of the American Geophysical Union, 28, 285-290.

STORR, D. (1973) Wind-snow relations at Marmot Creek, Alberta. Canadian Journal of Forest Research, 3, 479-485.

STORR, D. and FERGUSON, H. L. (1972) The distribution of precipitation in some mountainous Canadian watersheds. In The Distribution of Precipitation in Mountainous Areas, Report No. 326, pp. 243-263. World Meteorological Organisation: Geneva.

SUTHERLAND, D. G. (1984) Modern glacier characteristics as a basis for inferring former climates with particular reference to the Loch Lomond Stadial. Quaternary Science Reviews, 3, 291-309.

TABLER, R. D. (1975) Predicting profiles of snow-drifts in topographic catchments. In Proceedings of the Western Snow Conference, 43rd. meeting, pp. 87-97.

TABLER, R. D. and SCHMIDT, R. A. (1972) Weather conditions that determine snow transport at a site. In International Symposium on the Role of Snow and Ice in Hydrology. Proceedings (Banff, Canada, Sept. 6-13, 1972), pp. 118-127. UNESCO: Paris.

TAKEUCHI, M. (1980) Vertical profile and horizontal increase of drift-snow transport. Journal of Glaciology, 26 (94), 481-492.

TAYLOR, J. A. (1976) Upland climates. In Chandler, T. J. and Gregory, S. (Eds.) The climate of the British Isles, pp. 264-287. Longman: London.

THOM, A. S. (1974) Meteorological report. In Parnell, B. K.(Ed.) Aonach Mor. A planning report on the prospect of winter sport development at Fort William. Scottish Tourist Board: Edinburgh.

THOMAS, I. L., LEWIS, A. J. and CHING, N. P. (1978) Snowfield assessment from Landsat. Photogrammetric Engineering and Remote Sensing, 44, 493-502.

THOMAS, T. M. (1961) Late-lying snow in South-East Wales. Weather, 16, 171-180.

TRAVIS, A. S. (1974) A strategic appraisal of Scottish tourism: an assessment of resource potential. Scottish Tourist Board: Edinburgh.

UNWIN, D. J. (1977) Statistical methods in physical geography. Progress in Physical Geography, 1, 185-221.

U. S. ARMY CORPS OF ENGINEERS (1956) Snow hydrology: summary report of the snow investigations. U.S. Army Corps of Engineers, North Pacific Division: Portland.

U. S. FOREST SERVICE (1973) Planning considerations for winter sports resort development. U.S. Forest Service: Washington, D.C..

U. S.FOREST SERVICE (1975) Forest Service Manual. Title 2300 - Recreation Management. R-9 Supplement No.31. U.S. Forest Service: Washington, D. C..

VEDENIN, Y. A. and MIROSHNICHENKO, N. N. (1970) Evaluation of the natural environment for recreation purposes. Soviet Geography, 11, 198-207.

VINCENT, P. J. and LEE, M. P. (1982) Snow patches on Farleton Fell, South-East Cumbria. The Geographical Journal, 148, 337-342.

WAHL, E. (1966) Windspeed on mountains. Final Report AFCRL - 66 - 280. Department of Meteorology, University of Wisconsin: Milwaukee.

WALDER, U. (1983) Ausspperung und Vegetationsverteilung im Dischmatal. Mitteilungen, 59, Heft. 2. Eidgenossiche Anstalt fur das Forstliche Versuchswesen: Birmensdorf.

WARD, R. G. W. (1981) Snow avalanches in Scotland with particular reference to the Cairngorm Mountains. PhD thesis. University of Aberdeen: Aberdeen.

WARING, E. A. (1981) The assessment of snowfall receipts in Wales. PhD thesis. University College, Wales: Aberystwyth.

WATSON, A. (1975) The Cairngorms. Scottish Mountaineering Club District Guide. West Col Productions: Reading.

WATSON, A. and WATSON, R. D. (1984) Tourism, land use and rural communities in mountain areas. The Swiss approach and its relevance for Scotland. Grampian Regional Council: Aberdeen.

WEBSTER, R. (1977) Quantitative and numerical methods in soil classification and survey. Clarendon Press: Oxford.

WHITE, E.J. (1979) The prediction and selection of climatological data for ecological purposes in Great Britain. Journal of Applied Ecology, 16, 141-160.

WILLIAMS, L. D., BARRY, R. G. and ANDREWS, J. T. (1972) Application of computed global radiation for areas of high relief. Journal of Applied Meteorology, 11, 526-533.

WILLIAMS, P. (1982) Ski area financial performance: a comparative analysis. Recreation Research Review, May 1982, 22-28.

WILSON, W. V. (1981) The decline in the rate of ski facility development: changing American attitudes toward the environment and economic growth, 1968-1978. PhD thesis. University of Massachusetts: Boston.

WISHART, D. (1978) CLUSTAN User Manual. 3rd. Edition. Program Library Unit, University of Edinburgh: Edinburgh.

WOO, M. K. and MARSH, P. (1978) Analysis of error in the determination of snow storage for small High Arctic basins. Journal of Applied Meteorology, 17, 1537-1541.

WOO, M. K. and SAURIOL, J. (1980) Channel development in snow-fillesd valleys, Resolute, N.W.T., Canada. Geografiska Annaler, 62A, 37-56.

YAMADA, T. (1983) Studies on accumulation-ablation processes and distribution of snow in mountain regions, Hokkaido. Contributions from the Institute of Low Temperature Sciences (Japan), Series A, 31, 1-33.

YOSHINO, M. M. (1975) Climate in a small area: an introduction to local meteorology. University of Tokyo Press: Tokyo.

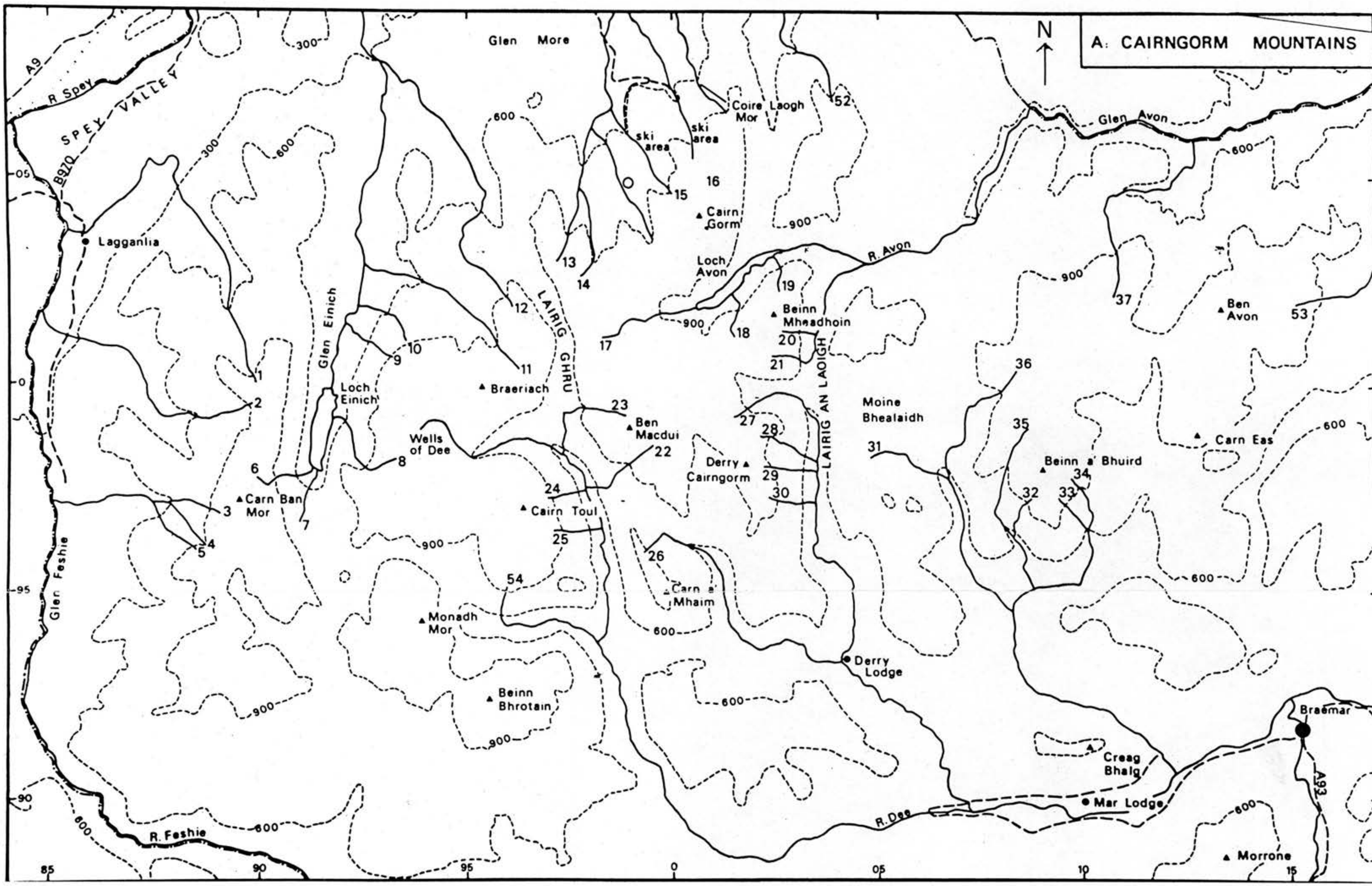
APPENDIX 1: LIST OF SITES USED IN THIS STUDY

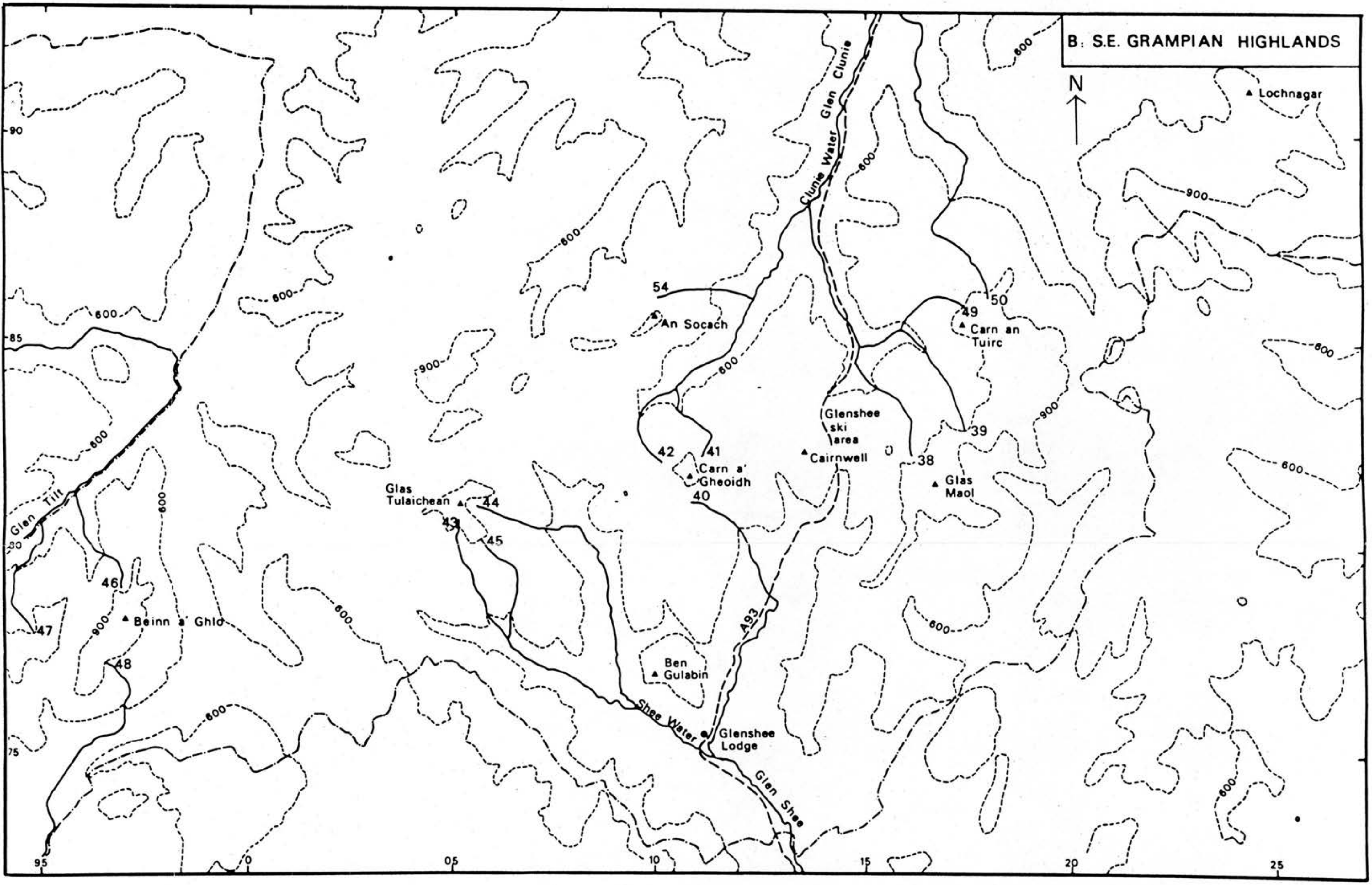
The 54 sites are all located within the Eastern Highland Scotland (see Chapter 1). The accompanying maps show the loca of each site within this area.

1 Allt a' Mharcaidh
2 Allt a' Chram-alltain
3 Allt Fhearnagan
4 Allt Meall Dubhaig
5 Allt a' Choire Ghuirm
6 Allt Fuaran Diotach
7 Allt a' Choire Odhair
8 Allt Coire Dhondail
9 Allt Buidheannach
10 Allt Easan na Bruaich
11 Beanaidh Bheag
12 Allt a' Choire Ghuirm
13 Allt Creag an Leth-choin
14 Allt Coire an Lochain
15 Allt a' Choire Chais
16 Allt na Ciste
17 Feith Buidhe
18 Allt Coire Buidhe
19 Allt Creag Dubh
20 Beinn Mheadhoin (Barns)
21 Beinn Mheadhoin (south)
22 Allt Clach nan Taillear
23 Allt a' Choire Mhoir
24 Allt Coire an t-Sabhail
25 Allt Toul
26 Allt a' Mhaim
27 Derry Cairngorm (north)
28 Allt an Lochain Uaine
29 Derry Cairngorm (2)
30 Derry Cairngorm (3)
31 Allt Clais nam Balgair
32 Allt a' Choire Ghuirm
33 Allt Iar-choire Sneachdach
34 Allt an t-Sneachda
35 Alltan na Beinne
36 Allt Coire Ruairidh
37 Allt Stob an t-Sluichd
38 Allt Coire Fionn
39 Allt a' Gharbh-choire
40 Allt Coolah
41 Allt a' Gheoidh
42 Allt a' Choire Chlachaich
43 Allt Clais Mhor
44 Allt Glas a' Choire Mhoir
45 Allt Clais Bheag
46 Allt Coire a' Chaisteil
47 Allt a' Coire Bhuidhe Mhoir
48 Allt Coire Lagain
49 Allt an Tuirc
50 Allt Bhealaich Bhuidhe
51 Buidheannach Burn
52 Allt a' Choire Dhuibh
53 Allt an t-Saighdeir
54 Allt Coire Fhearneasg

Location maps: key.

—·—·—·—·—	Boundary of the study area
— — — — — — —	Roads
▲	Mountains
o	Coire an t-Sneachda


A: CAIRNGORM MOUNTAINS
N
Glen More
R. Spey
A9
SPEY VALLEY
B970
Lagganlia
Glen Feshie
R. Feshie
Glen Einich
Loch Einich
Carn Ban Mor
Braeriach
LAIRIG GHRU
Wells of Dee
Cairn Toul
Monadh Mor
Beinn Bhrotain
ski area
Coire Laogh Mor
Cairn Gorm
Loch Avon
R. Avon
Glen Avon
Beinn Mheadhoin
Ben Macdui
Derry Cairngorm
Carn a' Mhaim
LAIRIG AN LAOIGH
Moine Bhealaidh
Derry Lodge
Beinn a' Bhuird
Ben Avon
Carn Eas
Creag Bhalg
Mar Lodge
R. Dee
Braemar
A93
Morrone
300
600
900
85
90
95
0
05
10
15



B: S.E. GRAMPIAN HIGHLANDS
N
Lochnagar
Glen Clunie
Clunie Water
54
An Socach
50
49
Carn an Tuirc
Glenshee ski area
Cairnwell
39
38
Glas Maol
42
41
Carn a' Gheoidh
40
Glas Tulaichean
44
43
45
A93
Ben Gulabin
Shee Water
Glenshee Lodge
Glen Shee
Glen Tilt
46
47
48
Beinn a' Ghlo
900
600
95
0
05
10
15
20
25
90
85
80
75

APPENDIX 2: GEOSTROPHIC WIND SPEED AND DIRECTION FOR EACH DAY IN WINTER OVER THE PERIOD 1954/5 TO 1984/5.

For each day, the speed and direction of the geostrophic wind are provided. Each value is a mean of two values measured from the weather charts published by the Meteorological Office (the times were 0000 and 1200 hours). The full procedure is described in sections 4.3.1 and 4.3.2. Although Chapter 4 is concerned only with the winters 1954/5 to 1983/4, data were required for 1984/5 for use in Chapters 7 and 8.

WINTER: 1954/5

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	22.0 SSW	12.0 SSE	15.0 SSE	25.0 SSW	11.5 NNW
2	26.0 SSW	7.0 SSE	17.0 ESE	14.0 SSW	20.0 SSE
3	30.0 WSW	15.0 ENE	10.5 SSE	20.5 SSW	14.5 WSW
4	33.0 WNW	22.0 ENE	12.0 WSW	19.5 WNW	13.0 SSW
5	16.5 WNW	13.5 ENE	9.5 NNW	20.5 NNW	11.5 SSE
6	12.0 WNW	12.0 ENE	11.0 NNW	15.0 NNE	9.0 SSW
7	11.0 WNW	9.0 ENE	13.5 WSW	8.0 NNE	12.0 SSW
8	18.5 ENE	7.5 WSW	17.0 NNW	11.5 NNE	9.0 WSW
9	27.5 ENE	11.5 SSW	11.5 NNW	8.5 NNE	13.0 SSW
10	12.0 WNW	8.5 NNW	20.0 NNW	7.0 WSW	15.0 WSW
11	9.5 SSE	12.5 WNW	18.0 NNW	12.5 WSW	14.0 WNW
12	21.5 SSE	33.0 NNW	18.5 NNE	10.5 WSW	15.5 WNW
13	12.0 WNW	18.0 WSW	12.5 NNE	9.0 NNE	14.5 WNW
14	19.0 SSW	10.0 WNW	14.5 NNW	12.0 WNW	7.5 NNW
15	19.5 WSW	11.0 WNW	10.0 NNW	14.0 WNW	6.5 SSE
16	26.0 SSE	13.0 WNW	22.0 NNW	11.5 NNW	5.5 ENE
17	18.5 WSW	14.5 WNW	25.5 NNW	22.0 NNW	5.0 ENE
18	24.5 WSW	13.0 WNW	11.0 NNE	14.5 NNW	5.0 SSE
19	14.0 WSW	8.0 WNW	7.0 NNW	11.5 NNW	7.5 NNE
20	26.5 WSW	16.5 SSE	8.5 NNW	20.5 WSW	8.0 WNW
21	34.0 WNW	23.0 SSW	9.5 NNE	16.0 SSE	7.5 NNW
22	21.5 WNW	11.5 NNW	14.0 NNE	13.0 SSE	12.0 WNW
23	32.5 WNW	14.0 WSW	13.5 ENE	21.5 ESE	10.0 WNW
24	15.0 WNW	29.5 SSW	11.0 ENE	12.5 ESE	9.5 NNW
25	17.0 SSW	24.5 SSW	14.0 ENE	7.5 SSE	17.5 SSE
26	28.5 WSW	17.5 WSW	6.0 ESE	11.0 ENE	7.5 SSE
27	27.5 WSW	13.0 WSW	16.0 SSE	9.5 ENE	18.5 SSE
28	12.5 WSW	11.5 WSW	27.0 SSW	9.0 NNW	11.5 WSW
29	11.0 WSW	14.0 WSW	--------	6.5 NNW	10.5 SSE
30	18.5 SSE	14.0 SSE	--------	12.5 WNW	13.0 SSW
31	16.5 SSE	13.5 SSE	--------	12.5 WNW	--------
Mean	20.5	14.6	14.1	13.5	11.2
S.D.	7.1	6.0	5.0	4.9	3.9

WINTER 1955/6

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	10.5 SSW	20.0 WNW	12.5 ESE	28.0 WSW	6.0 NNE
2	14.5 SSW	17.0 NNW	11.0 ESE	27.5 WNW	8.0 WSW
3	27.0 WSW	19.0 WSW	14.5 SSW	18.5 WNW	15.0 NNW
4	14.5 WSW	13.5 WSW	10.0 SSW	12.0 WNW	11.5 NNW
5	26.5 WSW	17.5 WSW	12.0 WSW	10.5 WNW	10.5 NNE
6	15.5 WSW	13.0 WSW	10.0 WNW	13.0 WNW	6.0 NNW
7	10.5 WSW	18.5 WSW	15.0 WSW	10.0 ESE	13.0 WSW
8	11.0 NNW	14.0 WSW	9.5 WSW	13.0 SSW	21.5 SSW
9	15.0 ESE	13.5 WSW	9.0 ENE	18.0 SSW	12.0 WSW
10	19.5 ESE	14.5 WNW	8.5 ENE	14.5 SSE	12.0 SSW
11	14.0 ENE	10.0 WNW	12.5 ENE	20.5 SSE	10.0 WNW
12	13.5 SSE	15.0 WNW	13.5 NNW	23.5 SSE	5.0 NNE
13	20.0 SSE	12.5 WNW	18.5 NNW	16.5 SSE	5.5 NNE
14	28.0 ESE	10.0 NNW	10.5 NNE	12.5 SSE	5.0 NNE
15	6.5 ESE	12.5 WSW	14.5 NNW	17.0 SSE	7.5 NNW
16	12.5 SSE	19.0 WSW	10.0 NNW	12.0 SSE	10.5 NNW
17	10.0 ENE	24.5 WNW	5.0 NNW	17.0 ESE	10.0 NNW
18	15.0 NNW	21.0 WSW	6.5 ENE	16.5 ESE	5.0 NNW
19	7.5 NNW	15.0 WSW	8.5 ENE	21.5 ESE	5.0 NNW
20	13.0 NNE	23.0 WSW	9.0 NNE	20.0 ESE	9.5 SSW
21	13.0 WNW	28.5 WNW	13.0 ENE	19.5 ESE	21.5 SSE
22	18.0 SSE	15.0 WNW	10.5 ENE	18.0 ESE	15.0 SSE
23	33.0 SSE	10.0 SSW	7.5 NNE	19.0 ESE	7.5 SSE
24	16.0 WSW	14.0 WNW	7.5 ENE	16.0 ESE	7.5 ESE
25	17.0 SSW	9.0 NNW	5.0 NNW	20.0 SSE	7.5 ENE
26	20.0 WSW	14.0 SSE	10.5 WSW	13.5 SSE	10.0 ENE
27	27.5 WSW	11.5 SSE	12.5 WSW	10.0 ENE	11.0 NNE
28	30.5 WSW	20.0 SSE	11.5 WSW	11.0 ENE	10.0 ENE
29	28.0 WNW	22.5 SSE	20.5 SSW	10.0 ENE	10.0 ENE
30	11.5 WNW	10.0 SSE	--------	7.5 NNW	9.5 ESE
31	23.0 WNW	17.0 ESE	--------	9.0 NNW	--------
Mean	17.5	16.0	11.0	16.0	9.6
S.D.	7.0	4.7	3.5	5.1	4.5

WINTER 1956/7

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	14.0 WNW	14.0 ESE	20.5 WSW	20.5 SSW	13.5 SSE
2	27.0 WSW	15.5 ESE	22.0 SSW	12.5 SSW	10.0 SSE
3	15.0 WNW	13.5 SSE	28.5 SSE	7.5 WSW	18.0 SSE
4	21.5 WNW	17.0 SSE	14.0 SSE	10.5 ESE	10.5 SSW
5	18.0 WSW	20.5 SSE	10.0 NNW	12.5 ESE	6.5 WNW
6	10.5 WNW	21.5 WSW	10.0 WNW	14.5 SSE	8.5 NNE
7	12.5 WSW	27.5 SSW	15.0 SSE	9.0 SSE	9.0 NNE
8	12.0 WSW	29.0 WSW	19.5 SSW	14.5 SSE	10.0 NNE
9	18.0 SSW	28.0 WSW	22.0 WSW	21.5 SSE	7.5 NNW
10	22.5 SSW	18.0 WNW	10.0 WSW	10.5 SSE	11.0 NNW
11	12.5 SSW	15.5 WSW	12.5 SSW	13.5 SSE	15.0 NNW
12	24.5 SSW	19.0 WNW	8.0 WSW	13.0 SSE	12.5 NNW
13	33.0 WSW	12.5 NNW	15.0 ENE	7.0 SSW	8.0 NNW
14	20.5 SSW	9.0 NNE	10.5 ENE	15.0 WSW	9.0 WSW
15	24.0 SSW	7.0 NNE	10.0 WNW	14.5 WSW	15.5 WSW
16	27.0 WSW	7.5 WNW	10.0 WNW	17.5 WSW	12.5 WSW
17	31.0 SSW	10.0 WNW	9.5 WNW	24.0 WSW	12.0 SSW
18	15.0 SSW	8.0 WSW	13.0 WNW	17.5 WNW	25.5 WNW
19	17.5 SSW	15.5 SSW	14.5 WSW	14.0 ESE	12.5 WNW
20	9.0 SSW	33.0 SSW	13.0 WSW	19.0 SSW	11.5 SSW
21	12.0 SSW	20.5 WSW	7.5 WSW	16.0 WSW	15.5 SSW
22	10.0 SSW	10.0 WSW	7.5 ESE	10.0 SSW	9.0 SSW
23	17.0 ESE	22.0 SSE	21.0 ESE	16.5 SSE	5.0 SSW
24	18.0 ESE	15.0 SSW	19.0 ESE	12.0 SSE	5.0 WNW
25	21.0 ESE	16.5 WSW	10.0 NNE	11.5 SSW	5.0 NNE
26	17.5 ESE	20.0 WSW	10.0 NNW	13.0 SSW	5.0 NNE
27	15.5 SSE	25.5 WSW	11.0 SSE	10.0 WNW	5.0 NNE
28	29.5 ESE	29.0 SSW	22.5 SSW	10.0 WNW	5.0 NNW
29	10.0 SSE	12.0 WSW	--------	14.0 ESE	8.5 NNW
30	16.5 ESE	18.5 SSE	--------	14.5 SSE	11.5 NNW
31	31.5 SSE	21.0 SSE	--------	12.0 SSE	--------
Mean	18.8	17.8	14.1	13.8	10.4
S.D.	6.8	6.8	5.5	3.9	4.5

WINTER 1957/8

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	9.0 SSE	10.0 WNW	20.0 SSW	9.0 WSW	16.0 ESE
2	9.5 SSW	8.5 NNW	20.0 WSW	10.0 WSW	9.0 ESE
3	22.0 WSW	8.5 SSE	11.5 WSW	14.5 WSW	13.0 ESE
4	19.5 SSW	20.0 SSE	22.0 WSW	17.5 WSW	17.5 ENE
5	11.5 SSW	19.0 SSW	20.0 WNW	16.5 WSW	16.5 ENE
6	17.0 SSW	12.5 SSW	16.5 WNW	21.5 WNW	9.0 ENE
7	17.0 WSW	10.5 WNW	9.0 NNW	23.5 WNW	9.0 NNW
8	14.5 WNW	11.0 WSW	25.5 ESE	16.5 NNE	9.0 NNW
9	20.5 NNW	26.5 WSW	12.0 WNW	11.5 NNE	11.5 NNW
10	20.5 SSE	19.0 SSW	13.5 ESE	11.5 NNW	10.0 NNW
11	27.5 ESE	16.0 WSW	22.0 ESE	10.0 NNW	10.0 ENE
12	22.0 ENE	14.0 WNW	10.5 WSW	10.0 NNE	6.5 WNW
13	16.0 ENE	12.5 WNW	18.0 WSW	12.0 ESE	7.5 WNW
14	7.5 ENE	17.5 WSW	10.0 SSW	10.5 ESE	9.5 WSW
15	14.0 SSW	10.0 WSW	7.5 WSW	10.5 SSE	10.5 NNW
16	20.5 WSW	14.5 WSW	17.0 WSW	14.5 SSE	12.0 NNW
17	9.5 SSW	21.0 WNW	14.0 NNW	14.0 ESE	12.0 WSW
18	20.0 SSW	16.5 WSW	18.5 NNW	10.5 ESE	12.0 WSW
19	24.0 WSW	17.5 WNW	18.0 WNW	8.5 ESE	12.0 SSW
20	23.5 SSW	11.5 NNW	16.5 WNW	9.5 ESE	19.0 WSW
21	29.5 WSW	12.5 NNW	11.0 NNW	10.0 ESE	12.5 WNW
22	23.0 WSW	17.5 WNW	12.0 WNW	15.5 ESE	8.5 WSW
23	14.0 WSW	13.0 WNW	10.0 ESE	15.0 SSE	10.0 SSW
24	9.0 WSW	5.0 WNW	20.5 ENE	16.0 ESE	11.0 SSW
25	18.0 WSW	23.5 SSE	14.5 ENE	13.5 ESE	15.0 SSW
26	29.0 WSW	19.5 SSE	13.0 NNW	11.5 ENE	16.0 WSW
27	25.0 SSW	22.0 SSE	16.0 WNW	19.5 ESE	14.5 WNW
28	24.5 WNW	18.0 SSE	15.5 WSW	19.5 ENE	13.0 WSW
29	20.5 WNW	10.0 SSE	--------	14.5 ENE	16.5 WSW
30	21.0 WNW	18.0 WSW	--------	15.0 ESE	11.0 WSW
31	12.5 WNW	26.5 WSW	--------	19.5 ESE	--------
Mean	18.4	15.5	15.5	13.9	12.0
S.D.	6.0	5.3	4.5	3.9	3.1

WINTER 1958/9

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	10.0 NNW	17.5 WSW	10.0 SSE	9.5 SSW	9.5 WNW
2	12.0 NNW	27.5 WSW	8.0 SSE	12.0 SSE	13.5 SSE
3	12.0 WSW	16.5 WNW	10.0 WNW	13.0 SSE	14.0 SSW
4	14.5 WSW	22.0 WNW	10.0 SSE	11.5 WSW	17.5 SSW
5	12.0 NNW	13.0 WNW	9.5 SSW	20.0 ESE	15.0 WSW
6	10.0 WNW	14.0 WNW	5.5 SSW	16.0 SSW	17.5 WSW
7	16.5 SSW	12.0 NNW	7.5 SSW	13.5 NNE	21.0 WNW
8	14.5 WSW	17.0 NNW	9.0 SSE	9.0 ENE	10.5 WSW
9	14.5 NNW	14.0 NNW	13.0 SSE	16.5 SSE	7.5 WNW
10	9.5 WNW	16.0 NNW	12.5 SSE	18.5 SSE	9.5 NNW
11	14.0 ESE	23.5 NNW	15.0 SSW	20.0 SSE	8.5 NNE
12	21.0 SSE	21.5 NNW	13.5 SSE	14.0 SSE	17.0 ESE
13	11.5 WSW	13.5 NNW	20.0 SSE	14.0 SSE	12.0 SSE
14	11.0 ESE	10.0 NNW	21.5 SSE	22.0 SSE	11.0 SSE
15	17.0 ESE	10.0 WNW	12.5 SSW	12.0 WSW	15.5 SSE
16	15.0 ENE	9.0 WNW	16.5 SSW	9.0 WSW	10.5 ESE
17	14.0 ENE	12.0 WSW	11.0 SSW	9.0 SSE	11.0 NNW
18	10.0 ENE	12.5 ESE	21.5 SSW	10.0 SSE	10.5 NNE
19	22.0 ENE	19.0 SSE	20.5 WSW	10.0 ESE	9.5 NNE
20	16.5 SSE	14.5 SSW	20.5 WSW	8.0 ESE	10.0 SSE
21	15.0 SSE	10.5 NNE	11.5 WNW	14.5 ESE	9.0 WNW
22	19.5 SSE	10.0 NNE	10.0 WNW	11.5 ESE	7.0 WNW
23	11.5 SSE	21.0 WNW	19.5 SSW	7.5 SSE	5.0 WSW
24	8.0 SSW	21.0 NNW	12.5 SSW	13.5 ESE	12.0 SSW
25	7.0 SSW	10.5 WNW	22.0 WSW	12.0 SSE	9.5 SSE
26	17.0 SSW	13.0 WSW	30.0 SSW	15.5 WSW	19.5 SSE
27	19.0 WNW	14.5 SSW	15.0 SSW	17.0 SSE	12.5 WSW
28	15.5 SSW	14.0 SSE	21.5 SSW	14.0 WSW	10.0 ENE
29	27.0 WSW	9.5 WSW	--------	18.0 SSE	13.0 WSW
30	25.5 WSW	7.5 NNW	--------	10.0 SSE	11.5 WSW
31	14.0 WSW	10.0 NNW	--------	12.5 SSW	--------
MEAN	14.7	14.7	14.6	13.3	12.0
S.D.	4.7	4.8	5.7	3.7	3.7

WINTER 1959/60

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	11.5 ESE	11.5 NNW	10.0 SSE	18.5 WSW	10.5 ESE
2	15.5 SSE	10.0 SSE	26.0 SSE	11.5 WSW	20.0 SSE
3	19.0 SSE	10.5 SSE	15.0 SSE	11.5 WSW	18.0 SSE
4	12.0 SSW	17.0 SSW	18.0 SSW	13.5 NNW	21.5 ESE
5	10.0 SSE	20.0 WNW	7.5 WSW	17.0 SSE	27.0 SSE
6	15.0 SSE	15.5 WNW	5.0 WNW	19.0 SSE	15.0 SSW
7	34.0 SSE	20.0 ESE	10.0 SSW	14.5 SSE	9.5 SSW
8	25.5 ESE	10.0 SSE	5.0 SSW	18.0 SSE	14.0 SSW
9	26.5 ESE	7.5 ESE	9.5 WSW	17.0 ESE	17.0 SSW
10	12.5 ESE	11.0 NNW	12.0 NNW	18.5 SSE	12.0 SSW
11	17.5 ESE	16.0 NNW	10.5 NNW	10.0 ESE	17.5 WNW
12	13.5 SSE	7.5 NNE	12.5 NNE	10.5 ESE	16.5 WSW
13	14.5 SSW	11.0 NNE	10.5 NNE	10.5 ESE	26.0 WSW
14	17.0 SSW	12.5 NNE	20.0 WSW	11.0 ESE	33.5 WSW
15	14.5 WSW	10.5 NNE	29.0 WNW	19.0 SSE	17.0 WNW
16	12.0 SSW	15.0 NNW	22.0 WNW	10.0 SSE	10.0 WNW
17	24.0 SSE	14.5 NNW	25.0 NNW	10.0 SSE	12.0 SSW
18	27.0 WNW	12.5 ENE	12.5 ENE	16.5 SSE	10.0 SSW
19	20.5 WNW	22.5 ENE	14.0 ESE	19.0 ESE	5.0 SSE
20	22.0 WSW	17.5 NNE	19.5 WSW	20.0 SSE	13.5 SSW
21	17.5 WNW	26.0 SSE	20.5 WSW	15.0 SSE	9.5 WSW
22	10.5 SSE	27.5 SSE	7.5 WSW	14.0 SSE	13.5 WNW
23	13.5 SSE	16.0 SSW	5.0 NNW	13.0 SSE	9.5 WNW
24	14.0 SSW	10.0 WSW	9.5 SSW	16.0 SSE	9.0 WNW
25	9.5 SSE	8.5 WSW	21.5 SSE	11.5 SSE	9.0 NNW
26	17.5 ESE	8.5 SSE	9.5 SSE	11.0 ESE	7.5 WNW
27	11.5 SSW	7.0 ESE	25.0 SSE	13.0 ENE	5.0 NNW
28	14.5 NNW	10.0 ESE	12.0 SSW	8.0 ENE	5.0 NNW
29	16.5 SSE	11.0 NNE	15.5 SSE	8.5 ENE	5.0 ENE
30	24.5 WNW	10.0 WNW	--------	12.0 ENE	7.5 ENE
31	15.5 WSW	12.5 ESE	--------	8.0 ENE	-------
Mean	17.1	13.5	14.5	13.7	13.5
S.D.	5.8	5.2	6.7	3.6	6.8

WINTER 1960/1

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	20.0 WSW	13.0 SSW	11.0 NNW	12.0 SSW	10.0 NNW
2	14.0 WSW	15.5 SSW	7.5 NNE	18.0 SSW	9.5 NNE
3	31.0 WSW	16.0 NNW	10.0 NNW	20.0 SSW	10.5 WNW
4	23.5 WSW	20.5 NNW	10.0 NNE	17.5 SSW	7.5 SSE
5	23.5 WNW	15.0 WNW	9.0 SSE	11.0 SSW	9.5 ESE
6	10.0 WSW	13.5 NNW	13.5 SSW	14.5 SSW	8.0 ESE
7	13.5 SSE	16.5 SSE	26.0 WSW	11.0 SSE	7.5 ENE
8	11.5 ESE	17.0 NNW	18.5 SSE	12.5 SSW	14.5 SSE
9	5.0 ESE	12.5 WSW	25.0 WSW	16.0 SSW	12.0 SSE
10	10.0 SSW	9.5 NNE	23.5 SSW	19.5 SSW	9.0 SSE
11	9.5 SSW	10.0 WSW	15.5 SSW	12.5 SSW	7.0 SSW
12	11.5 WSW	25.5 SSW	14.0 WSW	16.5 WSW	20.0 SSW
13	9.5 WSW	9.5 WSW	15.0 SSW	11.5 WSW	14.0 SSW
14	7.5 SSE	8.0 WSW	16.5 SSW	19.5 WSW	10.5 WSW
15	10.0 SSW	10.0 WSW	9.0 SSW	15.5 WSW	10.5 WSW
16	20.0 SSW	8.5 SSE	17.5 SSW	16.0 WSW	9.0 SSE
17	16.5 WSW	13.0 SSE	21.5 SSW	12.0 WSW	10.5 SSW
18	10.0 WSW	18.0 SSE	17.0 SSW	22.0 WNW	10.0 ENE
19	8.5 WSW	15.0 SSE	16.5 SSW	17.5 NNW	15.0 ESE
20	11.5 NNW	7.5 WSW	16.5 WSW	27.5 WNW	16.0 SSE
21	10.0 NNW	11.5 ESE	10.0 SSE	13.0 NNW	17.5 SSE
22	13.0 WSW	12.5 ESE	11.5 SSE	16.5 NNW	14.0 SSE
23	19.0 WSW	11.5 SSE	11.5 SSE	15.5 WSW	11.0 ENE
24	9.0 WNW	14.5 SSE	13.5 ESE	16.0 WSW	8.5 WSW
25	14.5 WSW	17.5 ESE	12.5 SSE	21.5 WSW	9.5 ESE
26	27.5 SSW	24.5 SSE	28.0 SSW	23.5 WSW	18.0 ESE
27	28.5 WSW	33.0 SSE	23.0 WSW	22.0 WNW	13.0 ENE
28	17.5 WSW	14.5 WSW	19.0 WNW	20.5 WNW	10.0 ENE
29	9.0 SSW	26.0 ESE	--------	20.0 WNW	10.0 ENE
30	19.0 SSE	18.0 WSW	--------	10.0 ENE	9.0 SSE
31	10.0 SSE	18.5 WSW	--------	22.5 NNW	--------
Mean	14.6	15.4	15.8	16.9	11.4
S.D.	6.6	5.7	5.5	4.3	3.3

WINTER 1961/2

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	12.0 WNW	14.0 WNW	18.0 WNW	13.5 NNW	29.5 WSW
2	20.0 WNW	9.0 WSW	19.5 WNW	16.5 NNW	19.0 SSE
3	27.0 NNW	8.0 WSW	18.0 WSW	9.0 NNE	11.5 NNE
4	13.5 NNE	18.0 WSW	21.5 WNW	10.0 NNE	13.0 SSE
5	19.5 NNE	21.0 WSW	19.0 WNW	5.5 NNE	12.0 WNW
6	19.5 WNW	9.0 WSW	20.0 SSW	5.0 NNW	12.5 WNW
7	17.0 WNW	25.0 SSW	15.5 SSW	11.0 SSE	11.5 WSW
8	14.0 SSE	20.0 SSW	21.0 NNW	27.5 SSE	13.0 ENE
9	12.5 SSE	26.0 WSW	24.0 WSW	9.5 ESE	15.0 WNW
10	13.5 SSE	24.5 WSW	19.0 WSW	7.5 ENE	12.0 WNW
11	15.0 SSE	19.5 SSE	26.0 WSW	8.0 ENE	21.0 WSW
12	17.0 WSW	27.5 WNW	39.0 WNW	11.0 NNE	17.5 WNW
13	9.5 SSW	16.5 WNW	20.5 NNW	11.0 NNW	15.0 NNW
14	14.0 WSW	9.5 WNW	22.5 NNW	17.0 NNW	5.0 ENE
15	26.5 SSW	22.5 SSE	21.0 WNW	7.5 WNW	7.0 ENE
16	18.5 SSW	23.0 SSW	40.5 WNW	9.0 ESE	10.0 ENE
17	9.0 SSW	29.5 SSW	21.0 WNW	7.5 SSE	16.0 ENE
18	10.0 SSW	17.0 NNW	20.0 WNW	5.0 SSW	12.5 ENE
19	5.0 ENE	19.0 SSW	12.5 WSW	7.5 NNW	12.5 ENE
20	5.0 NNW	15.5 WSW	8.5 WSW	9.5 NNE	11.5 ESE
21	5.0 WNW	18.0 SSW	9.5 SSW	8.5 NNW	14.0 SSE
22	7.5 ESE	32.0 WSW	8.5 SSW	10.0 NNW	11.0 WNW
23	10.0 ESE	24.5 WNW	8.0 SSE	7.5 NNE	9.5 SSE
24	10.0 ESE	11.5 SSE	8.5 ESE	16.0 NNE	7.5 ESE
25	10.0 ENE	9.0 ENE	14.0 ENE	21.0 SSW	10.0 SSW
26	9.0 ENE	16.0 SSW	16.0 ENE	15.0 ENE	14.5 SSW
27	15.0 SSW	11.0 WNW	15.0 ENE	15.0 NNW	10.0 NNW
28	14.0 ENE	9.5 WSW	10.0 ENE	13.5 NNW	10.0 NNW
29	12.0 ENE	18.5 SSW	--------	14.0 SSE	10.0 ENE
30	14.0 ENE	24.0 WSW	--------	13.0 WNW	5.0 ESE
31	17.0 WNW	33.0 WSW	--------	16.5 WNW	--------
Mean	13.6	18.7	18.4	11.5	12.6
S.D.	5.4	7.0	7.8	4.9	4.7

WINTER 1962/3

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	14.5 SSW	28.0 ENE	13.0 ENE	18.0 SSW	22.0 SSE
2	15.5 SSW	13.5 ENE	9.0 ENE	15.0 SSW	12.5 WSW
3	9.5 SSW	18.5 ENE	12.5 NNE	15.0 SSE	8.0 NNW
4	9.5 SSW	18.5 ENE	9.5 NNW	13.5 SSE	16.0 ENE
5	16.5 SSW	14.0 ENE	15.0 ESE	27.5 SSE	14.5 ENE
6	15.5 SSW	11.5 ENE	34.0 ESE	28.0 WSW	19.5 ENE
7	16.0 SSW	12.5 ESE	24.5 ESE	18.0 WSW	11.0 ENE
8	20.5 WSW	10.0 ESE	14.0 ESE	12.5 ESE	20.5 ENE
9	23.0 WNW	11.5 ENE	12.0 ESE	21.0 SSE	12.5 ENE
10	18.0 NNW	9.5 ENE	11.5 ESE	21.5 ESE	8.5 ESE
11	21.0 WSW	8.0 WNW	9.0 ENE	8.0 ESE	11.0 WNW
12	14.0 NNW	10.0 NNW	10.0 NNW	5.0 NNW	22.0 WSW
13	21.5 NNE	14.0 WNW	10.0 ESE	9.5 ESE	32.0 WSW
14	19.0 WSW	13.5 NNW	27.5 ESE	26.0 ESE	17.5 WSW
15	20.0 WNW	12.5 WNW	19.0 ESE	21.5 SSW	9.5 NNW
16	21.0 NNW	10.0 ENE	12.0 ESE	23.0 ESE	16.5 ESE
17	13.0 NNW	9.5 NNE	9.0 NNW	20.0 SSW	16.5 SSE
18	11.5 WNW	12.5 WNW	7.5 WNW	17.0 SSE	10.0 ESE
19	12.0 WNW	8.5 ESE	5.0 WNW	10.0 SSE	10.0 ESE
20	18.0 SSW	21.5 ESE	7.5 WNW	10.0 SSE	11.5 ESE
21	13.5 WNW	16.5 ESE	10.0 WNW	10.0 SSE	26.0 ESE
22	18.5 SSW	10.5 SSW	6.5 WSW	5.0 ENE	23.5 SSE
23	16.5 SSW	13.0 WSW	11.5 SSW	7.5 WSW	11.5 SSW
24	19.5 SSW	13.0 WSW	7.0 SSW	25.0 SSW	9.0 ESE
25	12.5 SSW	17.5 WSW	13.5 SSW	18.5 WNW	7.5 SSE
26	13.5 ENE	11.0 WSW	14.5 SSW	9.0 WSW	7.0 SSE
27	12.5 NNE	10.5 WNW	18.0 SSW	12.5 SSW	11.0 SSW
28	8.5 NNE	10.0 WSW	14.5 SSW	14.5 SSW	12.0 WSW
29	6.0 ENE	12.0 WSW	--------	16.5 SSE	17.0 WSW
30	20.0 ENE	13.5 ENE	--------	16.0 ENE	13.5 WSW
31	30.0 ENE	12.0 ENE	--------	12.5 SSW	--------
Mean	16.1	13.1	13.1	15.7	14.7
S.D.	4.9	4.1	6.4	6.3	6.0

WINTER 1963/4

	DECEMBER	JANUARY	FEBRAURY	MARCH	APRIL
1	12.5 ESE	15.0 SSE	28.0 WSW	11.5 SSE	7.5 ENE
2	13.5 ESE	25.5 SSW	20.5 WSW	10.0 SSE	6.5 NNE
3	14.0 ENE	22.0 SSW	25.0 WSW	10.0 WNW	9.5 ENE
4	14.5 ENE	9.0 SSW	18.5 WSW	9.5 ENE	9.5 ENE
5	9.0 ESE	10.0 NNE	17.5 NNW	7.5 ENE	8.5 WNW
6	7.5 ENE	12.0 SSE	9.0 WNW	5.0 ENE	9.0 NNW
7	8.0 ENE	10.5 WSW	12.5 WNW	5.0 NNE	9.5 WNW
8	8.0 SSE	13.0 WSW	12.0 WNW	5.0 WNW	11.0 WSW
9	8.5 SSW	11.0 SSW	13.0 WNW	10.0 WNW	15.5 WSW
10	10.0 SSW	10.0 SSW	18.0 WSW	8.5 NNE	8.5 WSW
11	10.0 SSE	10.0 SSW	16.5 WNW	11.0 ESE	13.0 WSW
12	11.5 ESE	10.0 SSW	10.0 WSW	13.5 ESE	17.0 WSW
13	9.0 WSW	10.5 ENE	13.0 SSE	24.0 ESE	15.0 WSW
14	11.0 NNW	14.5 ENE	13.5 SSE	27.0 SSE	17.0 WSW
15	9.0 NNW	14.5 SSE	13.0 SSE	24.5 ESE	19.0 WSW
16	10.5 NNE	10.5 SSE	14.0 SSE	15.5 SSE	12.0 WSW
17	15.0 ENE	12.0 SSE	10.5 ENE	24.5 SSE	10.5 ESE
18	14.0 NNW	15.0 SSW	17.0 ENE	21.5 SSE	10.0 ESE
19	17.5 WNW	15.0 SSW	9.5 ENE	27.0 ESE	13.0 ENE
20	10.5 WNW	17.0 WSW	7.0 SSE	14.0 SSE	12.5 ENE
21	15.5 WNW	15.5 WSW	10.0 SSE	13.5 SSE	15.5 ESE
22	10.0 WNW	9.5 WSW	20.5 SSE	8.0 ESE	11.5 ESE
23	25.5 SSW	14.0 WSW	22.5 SSE	12.5 ESE	7.5 NNE
24	31.0 SSW	13.5 WNW	18.5 SSE	25.0 SSE	10.0 NNE
25	27.5 SSW	17.5 WSW	24.5 ESE	16.0 WNW	17.5 SSE
26	20.5 WSW	17.5 WSW	16.5 SSE	13.0 WNW	11.0 SSW
27	16.0 SSW	17.5 SSW	14.5 SSE	13.0 ESE	11.5 SSE
28	22.5 SSW	13.0 WSW	14.5 SSW	14.0 SSE	14.0 SSE
29	24.5 SSW	19.0 WSW	13.5 SSE	11.0 ESE	15.5 WSW
30	27.5 WSW	18.0 WSW	--------	9.0 ESE	13.0 WSW
31	14.5 WSW	18.5 WNW	--------	10.5 ENE	--------
Mean	14.8	14.2	15.6	13.9	12.0
S.D.	6.5	3.9	5.1	6.5	3.3

WINTER 1964/5

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	8.0 WSW	12.5 WNW	10.0 NNW	18.0 ENE	10.0 ESE
2	15.5 WSW	13.5 WNW	10.5 WNW	15.5 WSW	7.0 SSW
3	19.5 NNW	12.5 WNW	8.5 WNW	28.5 SSW	10.0 WSW
4	16.5 WNW	14.0 WNW	9.5 WNW	12.0 ESE	6.0 WSW
5	11.0 WSW	18.5 WSW	14.5 WNW	7.5 NNE	5.0 ESE
6	22.0 WSW	15.5 WSW	8.5 WNW	5.0 WSW	6.0 WSW
7	15.0 WSW	14.5 WSW	12.0 NNW	19.5 WSW	8.0 ESE
8	24.5 WSW	13.5 WSW	9.0 NNE	5.5 WNW	11.0 SSE
9	19.0 WSW	15.5 WSW	11.0 WNW	9.0 SSW	15.0 SSE
10	13.5 WSW	17.0 SSW	11.5 WNW	10.0 SSW	19.5 WSW
11	20.5 SSW	20.0 SSW	12.0 WSW	11.0 SSE	24.0 WSW
12	22.0 SSW	20.5 SSW	22.0 WSW	11.0 SSE	13.5 WSW
13	12.5 NNW	16.5 WSW	30.0 WNW	13.5 SSE	13.5 WNW
14	9.0 NNW	24.0 WNW	19.5 NNW	9.5 SSW	12.0 SSW
15	11.5 WSW	14.5 WSW	13.5 WNW	14.0 SSE	14.0 WSW
16	16.5 SSE	16.5 WSW	8.0 WNW	23.5 SSW	15.0 WNW
17	14.0 NNE	17.5 WSW	6.5 NNW	26.5 WSW	21.5 WSW
18	9.0 NNE	13.5 WNW	9.0 NNW	11.5 NNW	18.5 WNW
19	8.5 WSW	7.5 WNW	12.0 ENE	8.5 WNW	19.5 NNW
20	10.5 NNW	9.0 ENE	10.5 ESE	8.5 ESE	14.0 NNE
21	6.5 NNW	12.5 SSE	8.5 NNE	13.0 ESE	9.0 SSE
22	5.0 ENE	13.0 SSE	9.5 NNE	15.5 ESE	8.5 SSE
23	9.0 WSW	18.0 SSE	8.5 WNW	14.5 ENE	6.5 WSW
24	12.0 NNW	9.0 WNW	11.5 ENE	6.5 ENE	9.5 WSW
25	18.0 NNW	7.5 WNW	12.5 NNW	14.0 ENE	12.5 WSW
26	12.0 WSW	9.0 NNW	17.0 NNW	12.0 ESE	13.5 WSW
27	10.5 SSW	9.0 ENE	12.0 WNW	16.5 WSW	12.5 NNE
28	18.5 WSW	6.0 NNE	18.0 WNW	15.0 WSW	10.0 ENE
29	19.5 WSW	7.0 ENE	--------	16.0 WSW	10.5 ENE
30	22.0 WSW	11.0 WNW	--------	11.5 ESE	8.5 ENE
31	20.5 WSW	9.0 WNW	--------	14.0 SSE	--------
Mean	14.6	13.5	12.3	13.4	11.8
S.D.	5.2	4.3	4.9	5.5	4.5

WINTER 1965/6

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	18.5 WNW	10.0 SSE	7.5 NNE	18.5 SSE	11.5 WSW
2	20.5 SSE	10.0 ENE	19.0 ESE	19.0 SSE	11.0 NNW
3	14.5 NNE	8.5 NNE	12.5 SSE	14.5 SSW	7.5 NNE
4	20.0 SSW	14.5 SSE	18.5 SSE	9.5 WSW	12.0 ESE
5	9.5 SSW	25.5 SSE	12.5 WSW	14.5 WSW	15.0 ESE
6	13.0 WNW	14.0 SSE	15.0 WSW	18.5 WSW	17.5 ESE
7	16.5 NNW	17.5 SSE	10.0 ENE	17.5 SSW	11.5 ESE
8	13.5 SSW	15.0 SSE	18.0 ESE	12.0 WSW	12.5 ESE
9	14.5 WSW	16.0 SSE	14.5 ESE	16.5 WSW	21.0 ESE
10	25.5 NNE	17.5 ESE	12.5 ESE	20.0 WNW	16.5 ESE
11	14.5 WNW	20.5 ESE	11.5 ENE	19.5 WNW	14.5 ESE
12	10.0 SSW	8.0 ENE	12.5 ESE	18.5 WNW	15.5 ESE
13	13.5 SSW	5.0 ESE	10.5 ESE	9.0 WNW	10.5 ESE
14	11.5 SSW	7.5 ESE	9.5 ENE	10.0 WNW	12.0 ENE
15	20.0 SSW	9.0 NNW	12.5 ENE	12.5 WNW	16.5 ENE
16	13.0 SSE	6.5 NNE	8.5 ENE	9.0 WSW	12.5 ENE
17	17.5 SSE	8.5 SSW	10.0 ENE	16.5 SSW	10.0 ENE
18	17.0 WSW	10.0 WSW	10.0 ESE	14.5 NNW	11.5 ESE
19	18.0 WSW	11.0 SSE	19.5 ESE	14.0 SSW	11.0 ESE
20	12.5 WSW	14.5 SSE	15.0 ENE	23.0 WSW	10.0 SSE
21	14.5 WNW	8.5 ESE	9.0 ESE	18.0 WNW	10.0 NNE
22	10.0 SSW	6.0 ENE	9.5 ESE	18.0 WNW	20.5 ESE
23	12.5 SSE	6.0 ENE	8.0 NNE	25.0 WNW	9.0 SSE
24	10.0 ENE	5.0 ESE	13.0 ESE	28.5 WNW	7.5 ESE
25	10.0 NNW	10.0 ESE	17.0 ESE	20.0 NNW	10.5 SSW
26	13.5 WNW	18.0 ESE	21.0 SSW	12.5 SSW	10.5 SSW
27	17.0 WNW	11.5 ESE	18.5 SSW	27.0 WNW	14.5 SSE
28	11.5 WNW	14.0 ESE	27.0 WSW	24.0 NNW	22.5 SSW
29	18.0 SSE	20.5 SSE	--------	18.0 WNW	24.0 WSW
30	12.5 WSW	22.0 WSW	--------	15.0 WNW	15.0 WSW
31	11.0 ESE	15.0 WSW	--------	15.0 WNW	--------
MEAN	14.6	12.4	13.7	17.0	13.5
S.D.	3.8	5.3	4.6	4.9	4.2

WINTER 1966/7

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	25.0 SSE	20.5 WNW	12.0 WSW	28.5 WSW	9.0 SSW
2	18.5 NNW	26.5 WNW	21.0 WSW	24.0 WNW	14.0 WSW
3	17.0 WNW	25.0 WNW	20.5 WSW	23.5 WSW	13.0 WSW
4	14.0 WNW	13.5 WNW	21.0 WSW	18.5 SSW	16.5 WSW
5	22.0 SSW	8.0 WNW	17.0 WSW	17.0 SSW	29.5 NNW
6	14.0 WSW	7.5 WNW	13.0 WSW	23.5 SSW	26.0 NNW
7	14.0 WSW	10.5 NNW	12.0 WSW	15.5 SSW	17.0 NNE
8	19.5 WSW	12.0 NNW	13.0 WSW	22.0 SSW	10.0 ENE
9	21.5 WSW	7.5 WSW	11.5 WSW	10.0 ENE	9.0 ENE
10	14.5 WSW	12.0 WSW	9.5 WSW	16.5 WSW	9.0 ENE
11	9.5 WNW	21.5 WNW	12.5 SSE	26.0 WSW	8.5 ENE
12	20.0 SSE	13.0 WNW	9.0 SSE	18.0 WSW	7.5 NNE
13	14.0 ENE	22.5 WNW	8.5 SSE	11.5 WSW	6.5 NNW
14	5.0 ESE	12.0 WSW	11.0 SSE	23.5 WSW	7.5 SSE
15	23.5 SSE	12.0 WSW	21.5 SSE	21.5 WNW	9.5 WNW
16	20.0 SSW	17.5 WSW	21.5 SSE	13.5 WSW	18.5 WSW
17	26.0 WSW	21.0 SSW	16.5 SSE	26.0 WSW	21.0 WNW
18	29.0 WSW	19.0 WSW	10.0 SSW	19.5 WNW	14.0 WNW
19	15.0 WNW	10.0 SSE	18.5 WSW	23.0 WNW	19.0 WNW
20	18.5 WNW	12.0 SSE	23.0 WSW	20.5 WSW	23.0 WNW
21	12.0 WNW	16.0 SSE	23.0 WSW	26.5 WSW	14.5 NNW
22	12.5 WSW	18.5 WSW	18.5 WSW	16.5 WSW	9.0 ESE
23	23.5 WNW	15.0 SSE	14.5 WNW	20.0 WNW	5.0 ESE
24	19.0 NNW	15.5 ESE	12.5 SSE	15.0 SSW	14.0 SSE
25	21.5 WNW	12.0 ESE	19.0 SSE	24.0 SSW	10.0 WNW
26	26.0 SSE	10.0 ESE	17.0 WSW	13.5 SSW	12.0 SSW
27	19.0 SSE	20.0 SSE	25.5 WSW	21.5 SSW	7.5 WSW
28	13.5 SSW	22.5 SSE	25.0 WSW	16.5 WNW	14.0 WNW
29	15.0 WSW	19.5 ESE	--------	23.0 NNW	14.0 NNW
30	11.5 WSW	14.5 SSE	--------	11.5 NNW	15.0 WNW
31	15.5 WSW	16.5 SSW	--------	9.0 NNW	--------
Mean	17.7	15.6	16.3	19.3	13.4
S.D.	5.3	5.1	5.1	5.1	5.8

WINTER 1967/8

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	9.5 WSW	10.0 SSW	15.5 WSW	5.0 ENE	10.0 NNW
2	11.5 SSW	12.0 NNW	12.0 WNW	7.0 WSW	17.5 NNW
3	17.5 WSW	15.0 NNW	12.0 NNW	12.0 WSW	22.5 NNW
4	20.5 WSW	11.5 WSW	24.5 SSW	20.5 WNW	17.0 NNW
5	17.0 WNW	6.0 WSW	12.5 SSE	21.0 WNW	14.0 WNW
6	20.5 NNW	10.0 WSW	21.0 ENE	21.0 NNW	9.5 NNW
7	20.5 WNW	14.0 NNW	16.5 ESE	7.5 NNW	9.5 NNW
8	19.5 WNW	11.0 SSW	17.0 ENE	11.5 NNW	12.0 WSW
9	13.0 WNW	13.5 ESE	17.0 ENE	13.0 NNW	6.0 WSW
10	12.0 NNW	15.0 NNW	9.0 ENE	13.0 NNW	6.0 SSE
11	18.5 WSW	12.5 NNW	9.0 ESE	15.5 NNW	9.0 SSE
12	14.0 WNW	13.0 SSW	6.0 SSE	11.0 WSW	7.5 SSE
13	10.5 WNW	17.0 SSW	10.0 WNW	14.5 WSW	9.0 ESE
14	16.5 WSW	16.0 WSW	7.0 ENE	11.0 WSW	6.5 ESE
15	23.5 WSW	27.5 WSW	6.5 NNE	11.5 WSW	10.5 ESE
16	14.5 NNW	15.0 SSE	9.0 WNW	19.0 WSW	22.5 ESE
17	13.0 WNW	13.5 WNW	9.5 WSW	27.0 WSW	18.0 ENE
18	7.0 WNW	15.0 WSW	11.5 WNW	21.5 WNW	9.5 ESE
19	7.5 WNW	14.0 WSW	6.5 WSW	16.5 WSW	8.5 WNW
20	11.5 SSE	16.0 WSW	5.5 NNE	9.0 SSW	6.5 SSE
21	13.5 WSW	5.5 WSW	5.5 ENE	8.5 WSW	7.0 SSE
22	19.0 SSW	5.0 ENE	8.5 ENE	10.5 WNW	9.5 SSE
23	8.0 WSW	16.0 NNW	7.5 WSW	16.0 SSE	8.0 SSW
24	11.0 NNW	17.0 WNW	9.0 WSW	9.0 WSW	7.0 SSW
25	13.0 NNW	21.5 WNW	6.0 ENE	9.5 SSW	9.5 SSW
26	8.5 WSW	16.0 WNW	5.0 ENE	17.5 WSW	10.0 SSW
27	11.0 WSW	16.0 WSW	10.5 WSW	26.5 WSW	14.0 SSE
28	19.0 NNE	16.5 WSW	13.5 SSW	12.0 WSW	12.5 ESE
29	18.0 NNE	20.5 WSW	16.5 SSW	6.0 SSE	9.0 ESE
30	15.0 WNW	14.5 WSW	--------	12.5 WSW	9.0 ENE
31	12.5 WNW	14.5 WSW	--------	13.5 WSW	--------
Mean	14.4	14.2	11.0	13.9	10.9
S.D.	4.4	4.4	4.9	5.6	4.4

WINTER 1968/9

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	13.0 ESE	17.0 WNW	12.5 SSW	10.0 ESE	16.5 NNW
2	16.5 SSE	20.0 WNW	26.0 NNE	9.0 ESE	8.5 NNW
3	17.0 SSE	13.5 WSW	15.0 NNW	12.0 NNE	12.0 WSW
4	16.5 SSE	14.5 WSW	15.0 WNW	8.5 WNW	10.0 WSW
5	8.5 SSE	14.0 WNW	19.5 WSW	5.0 WSW	9.0 WSW
6	9.5 SSE	7.0 WNW	16.5 WSW	7.5 WSW	5.0 WSW
7	8.0 SSE	21.5 ESE	15.5 NNW	5.0 NNW	10.0 WSW
8	9.0 SSE	21.0 ESE	19.5 WNW	22.5 WSW	10.0 WSW
9	12.0 SSE	16.5 SSE	14.5 NNW	10.5 WNW	11.0 WSW
10	12.0 SSE	22.0 SSE	6.5 WNW	10.5 NNW	12.5 WSW
11	5.0 SSW	14.0 SSW	14.0 WSW	12.5 ENE	10.5 WSW
12	19.0 SSW	10.0 ESE	13.5 NNW	12.5 ENE	15.5 WSW
13	24.0 SSW	19.0 ESE	10.0 NNW	21.0 ENE	15.0 NNW
14	10.0 SSE	10.0 WSW	17.5 NNW	21.0 ESE	18.0 WNW
15	16.5 SSE	10.0 SSE	10.5 ENE	20.0 ESE	17.0 WNW
16	12.5 SSE	11.5 SSW	10.0 SSE	18.0 ESE	18.0 WNW
17	15.0 ENE	15.5 SSW	10.0 WSW	18.5 ESE	10.0 NNW
18	17.0 NNE	15.0 SSE	10.0 ESE	21.0 ESE	7.5 ENE
19	11.5 ENE	10.0 ESE	13.5 ESE	16.0 ENE	11.0 ENE
20	23.5 SSE	14.0 ESE	13.0 ENE	13.5 SSE	11.0 ESE
21	11.0 WSW	21.0 SSE	17.0 ENE	15.5 SSE	20.0 ENE
22	25.5 SSE	8.0 SSW	15.5 ENE	13.0 SSE	23.0 ENE
23	27.5 WNW	10.0 NNW	14.0 ESE	10.0 ENE	9.0 ESE
24	20.0 NNW	14.0 SSW	21.5 ESE	10.0 NNW	16.5 SSE
25	11.0 NNW	22.0 SSW	14.0 ESE	10.0 ENE	9.5 SSW
26	13.0 NNW	13.5 SSW	9.0 ESE	7.5 ENE	8.0 SSW
27	14.5 NNW	17.5 SSE	10.0 ESE	5.0 WNW	12.5 WNW
28	16.0 NNW	10.0 WSW	12.0 ENE	10.0 WNW	11.0 WNW
29	18.0 NNW	10.0 WNW	--------	21.0 WSW	12.0 NNW
30	12.5 NNW	30.5 WSW	--------	17.0 WSW	8.5 NNW
31	9.0 NNW	17.0 WSW	--------	12.0 NNW	--------
Mean	14.6	15.1	14.1	13.1	12.3
S.D.	5.3	5.1	4.1	5.2	4.1

WINTER 1969/70

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	12.5 WNW	10.0 NNW	30.0 SSE	19.0 WNW	21.5 NNE
2	13.5 WNW	12.0 NNW	32.5 WSW	19.0 NNW	13.0 NNW
3	11.0 WNW	14.5 NNW	25.5 WSW	15.5 NNW	12.0 NNW
4	13.5 NNW	14.5 NNW	10.0 NNW	11.5 NNW	9.5 WNW
5	11.0 NNW	9.0 NNW	8.5 NNW	9.0 NNW	20.5 WSW
6	15.5 NNW	12.5 NNW	10.5 NNW	11.5 NNW	13.5 NNE
7	21.0 WSW	11.5 SSW	19.5 SSW	23.5 WNW	10.0 NNE
8	10.0 WNW	15.5 SSE	16.0 WSW	14.0 NNW	13.5 NNE
9	10.5 WNW	18.5 ESE	12.0 WSW	11.5 NNW	12.5 NNE
10	12.0 WNW	16.0 SSE	7.0 WNW	10.0 NNW	7.5 ENE
11	17.5 WSW	10.0 SSE	7.5 NNW	14.5 SSW	10.0 ENE
12	10.0 SSW	12.5 SSE	10.5 ESE	21.0 ESE	9.0 ESE
13	29.5 SSE	7.5 ESE	13.0 NNW	9.5 ESE	9.0 ESE
14	27.0 SSE	18.0 ESE	13.5 NNW	10.0 NNE	9.5 SSE
15	10.0 WSW	23.0 ESE	10.5 WNW	9.5 NNW	11.0 SSW
16	11.5 SSE	19.0 ESE	13.0 NNW	18.0 WSW	11.0 WSW
17	13.5 SSE	19.5 SSE	15.0 SSE	28.0 WSW	11.0 WSW
18	16.0 ESE	23.0 SSE	12.5 SSE	20.0 WNW	8.5 WSW
19	25.5 SSE	17.0 SSE	15.5 SSW	15.5 WNW	8.5 WSW
20	12.0 SSE	17.5 SSE	12.0 WNW	20.5 NNW	13.0 WSW
21	17.0 SSE	26.0 SSE	10.5 SSE	11.0 WSW	9.5 WSW
22	14.0 WSW	12.0 SSE	17.5 WSW	10.0 WSW	12.0 WSW
23	13.0 WSW	17.0 ESE	20.5 WSW	10.0 NNW	22.5 WSW
24	15.0 WSW	14.5 ESE	11.5 WNW	10.0 WSW	20.5 WNW
25	7.0 WNW	15.0 ESE	10.0 WNW	14.0 WSW	10.0 WNW
26	9.0 WNW	5.0 SSW	7.5 NNW	15.0 WNW	10.5 NNW
27	12.0 WNW	10.0 SSW	8.5 NNE	17.5 NNW	10.5 NNW
28	15.0 WSW	11.5 SSW	10.0 WNW	14.0 NNW	13.0 WNW
29	16.5 SSE	17.0 SSE	--------	13.0 WSW	18.5 NNW
30	13.5 ESE	11.0 SSE	--------	12.0 WSW	10.0 WSW
31	10.0 ENE	13.0 SSW	--------	22.0 NNE	--------
Mean	14.4	14.6	13.9	14.8	12.3
S.D.	5.1	4.6	6.4	4.8	4.1

WINTER 1970/1

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	10.0 NNW	6.5 NNW	6.5 NNW	13.5 SSW	9.0 SSE
2	8.0 WSW	5.0 NNW	15.5 WSW	10.0 WNW	10.0 ESE
3	13.0 WSW	5.0 WSW	17.5 WNW	8.0 ENE	8.0 ENE
4	14.5 WSW	7.0 WSW	12.0 WSW	11.0 SSE	11.0 ENE
5	18.5 WSW	12.5 WSW	5.0 WSW	9.5 NNE	7.5 ENE
6	23.0 WSW	21.5 SSE	7.5 WSW	6.0 NNE	7.5 ESE
7	15.5 WSW	27.5 SSW	8.5 WSW	5.0 NNW	5.0 ENE
8	13.5 WSW	15.5 SSW	16.5 WSW	10.0 NNW	5.0 ENE
9	9.0 WSW	21.0 SSE	9.5 WSW	15.0 NNW	5.0 ENE
10	7.0 WSW	25.0 WSW	18.0 SSW	8.5 NNW	5.0 ENE
11	10.0 SSE	14.0 SSE	11.0 SSW	10.0 SSE	5.0 WNW
12	13.0 SSW	11.0 SSE	20.0 WSW	13.5 WSW	7.5 NNW
13	12.0 WSW	6.5 SSE	21.5 WNW	14.0 WSW	6.5 ESE
14	12.5 WSW	5.0 SSE	20.0 WSW	8.5 WSW	5.0 ESE
15	17.0 SSW	5.0 SSW	20.5 SSE	7.5 WNW	5.0 WNW
16	14.0 SSW	7.5 SSW	5.0 ENE	7.5 WNW	17.0 WSW
17	21.5 WSW	12.5 SSW	7.5 SSE	7.5 WNW	14.5 WSW
18	13.5 WSW	16.0 SSW	10.0 SSE	11.5 ENE	18.0 WSW
19	12.0 WSW	13.5 SSE	9.5 SSW	22.5 ENE	11.0 WSW
20	12.0 WNW	12.0 SSW	14.5 SSW	18.5 ENE	14.0 WSW
21	9.5 WNW	18.5 ESE	13.5 WSW	12.5 NNE	10.5 SSE
22	11.0 NNW	11.5 SSE	8.5 WSW	10.0 NNE	12.5 SSE
23	15.5 NNW	16.0 SSE	13.0 WSW	12.5 WSW	20.5 ESE
24	11.5 ENE	11.0 SSW	14.0 NNW	15.0 WSW	15.0 ESE
25	8.5 ENE	10.5 SSW	5.0 WNW	12.5 WNW	8.5 ENE
26	12.0 NNE	10.0 SSW	5.0 SSE	14.0 WNW	7.5 NNE
27	8.5 ENE	12.5 ENE	10.5 SSE	7.5 ENE	10.5 NNE
28	8.5 ENE	10.0 ENE	15.0 SSE	17.5 SSW	12.0 NNW
29	14.0 ENE	10.0 ENE	--------	12.0 SSW	10.0 NNW
30	15.5 NNE	7.5 ENE	--------	10.0 SSW	10.0 SSW
31	7.0 NNW	17.0 ENE	--------	7.5 SSW	--------
Mean	12.6	12.4	12.2	11.2	9.8
S.D.	3.8	5.8	5.1	3.8	4.1

WINTER 1971/2

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	9.0 NNW	15.5 ESE	17.5 SSE	14.5 SSE	11.5 ESE
2	7.5 WSW	12.0 ENE	26.0 SSE	15.0 SSE	12.5 WSW
3	15.5 SSW	10.0 ENE	23.0 ESE	28.5 SSE	18.5 WSW
4	20.5 SSW	10.0 ENE	8.0 SSE	28.5 SSE	17.5 SSW
5	11.5 SSW	7.5 NNE	10.5 SSE	17.5 SSE	13.5 WSW
6	15.5 SSW	7.5 ESE	15.0 SSE	18.0 SSE	11.0 WSW
7	17.5 WSW	11.5 SSE	9.5 SSE	15.5 ESE	10.0 SSW
8	15.5 SSW	25.5 SSE	9.0 SSE	14.0 ENE	9.5 NNE
9	21.5 WSW	14.0 SSE	11.0 SSE	11.0 SSE	7.5 NNW
10	15.5 WSW	20.0 SSE	16.5 SSE	10.0 ESE	17.5 SSE
11	13.0 WSW	20.0 SSE	13.0 SSW	8.0 ESE	18.0 NNE
12	15.0 WSW	27.5 SSW	8.5 SSW	7.0 ESE	13.0 WNW
13	18.0 SSW	13.0 SSE	13.5 SSW	9.0 ESE	10.5 WSW
14	13.5 SSW	16.0 SSE	18.5 WNW	6.0 ESE	10.0 SSW
15	27.0 SSW	20.0 SSE	18.5 ESE	8.5 SSW	14.0 WNW
16	26.0 WSW	24.0 SSE	25.5 ENE	10.0 SSW	10.0 WSW
17	20.0 SSW	23.5 SSE	17.5 NNE	10.5 SSE	10.0 WNW
18	19.5 WSW	24.5 SSE	7.5 ESE	12.5 SSE	11.0 NNW
19	26.0 SSE	20.5 SSE	8.5 ESE	10.0 SSE	11.0 NNW
20	24.5 WSW	16.0 SSW	9.0 SSE	8.5 WNW	10.0 SSE
21	28.5 WSW	12.0 WSW	5.0 SSE	14.0 WNW	9.5 NNW
22	23.5 WSW	15.5 WSW	5.0 SSE	16.5 WNW	10.0 NNW
23	28.0 SSW	17.5 SSW	5.0 SSE	14.0 WNW	9.0 NNE
24	22.0 WSW	20.0 SSW	9.5 ESE	7.5 WSW	5.0 NNE
25	20.0 SSW	23.5 SSW	11.0 SSE	11.5 SSW	7.5 NNW
26	12.0 SSW	11.5 SSW	12.0 SSE	16.5 SSW	18.0 NNW
27	10.0 NNE	26.0 NNW	12.5 SSE	17.0 WSW	12.5 NNW
28	12.0 NNE	9.0 NNE	18.5 SSE	10.5 WNW	12.0 WSW
29	12.0 NNE	10.0 NNE	18.5 SSE	17.5 WNW	22.5 SSW
30	9.0 NNE	7.5 ENE	--------	12.0 SSW	17.5 SSE
31	9.5 NNE	8.5 ENE	--------	12.0 WSW	--------
Mean	17.4	16.1	13.2	13.3	12.3
S.D.	6.1	6.2	5.8	5.2	3.9

WINTER 1972/3

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	23.5 WSW	13.0 SSE	6.5 WNW	14.5 WSW	19.0 WNW
2	12.5 WSW	13.5 WSW	11.0 WSW	20.0 SSW	15.0 NNW
3	9.0 SSW	14.0 WSW	12.0 WSW	22.0 WSW	13.5 WNW
4	16.0 SSW	19.5 NNW	12.5 WSW	14.0 WSW	30.0 SSE
5	31.0 WSW	10.5 WNW	14.0 WSW	18.0 WSW	17.5 WSW
6	20.0 WSW	10.0 WNW	28.5 WSW	12.0 WSW	27.0 WSW
7	5.0 WSW	9.5 WNW	27.0 WSW	11.5 WNW	20.0 NNW
8	5.0 WSW	9.5 WNW	14.0 WSW	11.5 WSW	14.5 NNW
9	13.5 WSW	10.0 WNW	12.0 WSW	10.0 WSW	9.0 NNW
10	18.0 WSW	12.0 SSE	23.0 WSW	9.0 WSW	8.0 NNW
11	28.5 SSW	13.0 SSE	18.5 WSW	12.0 WSW	17.0 NNW
12	25.0 WSW	12.0 SSE	18.5 WNW	10.0 NNW	8.5 NNW
13	32.0 WSW	13.0 SSE	17.0 WNW	5.0 ENE	9.0 NNW
14	18.0 WSW	19.5 SSE	17.0 WSW	5.0 NNW	9.5 NNW
15	23.0 SSW	19.5 ESE	10.0 WNW	5.0 WSW	12.5 NNW
16	16.5 SSE	24.5 SSW	10.0 ENE	22.5 WSW	13.0 WNW
17	13.0 SSE	10.0 WSW	12.0 SSW	22.0 WSW	9.0 WNW
18	14.5 SSE	11.0 SSW	19.5 WSW	12.5 NNW	15.0 NNW
19	17.0 SSE	26.5 SSE	14.0 WSW	10.0 NNW	13.0 NNW
20	16.0 SSW	22.5 SSE	22.5 WSW	10.0 WNW	12.5 NNE
21	14.0 WSW	29.0 SSE	19.5 WSW	14.0 WSW	11.0 NNE
22	14.5 SSW	19.0 SSE	18.0 WNW	17.0 WSW	11.0 ENE
23	19.0 SSW	14.0 SSW	20.5 WNW	18.0 WSW	18.5 ENE
24	10.5 SSW	18.0 WSW	16.5 WNW	17.0 SSW	16.0 NNE
25	16.5 SSE	17.0 SSW	14.0 NNW	25.0 SSW	7.5 NNE
26	18.5 SSE	20.5 WSW	10.0 ENE	11.5 NNW	7.5 NNE
27	15.0 SSE	14.5 WNW	11.5 SSW	13.5 SSE	8.5 NNE
28	19.0 SSE	16.0 WSW	15.5 WSW	22.5 SSE	22.5 NNW
29	13.0 SSW	17.0 WSW	--------	16.5 WSW	22.0 WNW
30	20.0 SSW	19.5 WSW	--------	23.5 SSW	12.5 NNW
31	25.0 SSW	22.0 WSW	--------	21.0 WSW	--------
Mean	17.5	16.1	15.9	14.7	14.3
S.D.	6.4	5.2	5.2	5.6	5.7

WINTER 1973/4

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	10.0 ENE	19.0 SSW	18.0 SSE	18.0 SSE	15.5 SSE
2	12.5 WSW	25.5 SSE	14.5 SSE	10.0 WNW	11.0 ESE
3	19.5 WSW	19.0 SSE	14.5 SSW	11.0 NNE	10.0 ESE
4	19.5 WNW	24.5 SSE	10.0 WSW	13.5 NNE	10.0 ENE
5	13.0 WSW	26.0 SSE	18.0 SSW	10.0 ESE	8.5 ESE
6	23.5 WNW	15.5 SSE	9.5 NNW	16.0 SSE	8.5 ESE
7	15.5 ENE	22.5 SSE	18.0 NNW	21.0 SSE	7.0 ENE
8	21.5 WSW	17.5 SSE	14.5 SSE	19.0 SSW	8.0 ENE
9	18.5 WSW	12.0 WSW	13.0 WSW	16.0 ESE	10.0 ENE
10	22.0 WSW	26.0 SSE	18.5 SSW	13.0 ENE	10.0 ENE
11	21.0 WSW	24.5 SSW	20.0 SSW	10.0 ESE	11.5 ENE
12	23.0 SSW	34.0 SSW	15.0 WSW	12.5 ESE	10.5 ENE
13	23.0 WNW	21.0 SSE	10.0 WSW	11.0 ESE	8.5 ENE
14	17.5 NNW	23.5 SSW	10.0 SSW	8.0 ENE	7.0 NNE
15	23.5 WSW	15.0 WSW	21.0 SSE	11.0 ESE	6.5 NNW
16	24.0 WSW	16.5 SSW	16.5 SSE	12.5 WNW	5.0 NNW
17	25.0 WNW	21.0 WSW	12.0 NNW	23.0 WSW	5.0 NNE
18	14.0 SSW	26.5 WSW	13.0 SSW	16.5 SSW	5.0 NNE
19	23.0 ENE	21.5 WSW	10.0 SSW	11.5 SSW	5.0 ENE
20	19.5 ENE	19.5 SSW	20.0 WSW	10.0 WNW	5.0 ESE
21	10.0 ENE	19.5 SSW	18.5 WSW	10.5 SSW	5.0 ESE
22	11.5 ESE	10.5 SSW	20.5 SSW	11.5 SSW	7.0 WNW
23	13.5 ENE	23.5 SSW	10.5 WNW	14.5 SSE	9.5 NNW
24	10.0 ENE	16.5 SSW	15.0 WSW	9.5 ESE	10.0 NNW
25	17.0 SSW	21.0 SSW	11.0 SSW	13.5 ESE	10.5 NNE
26	13.5 WSW	22.0 SSE	5.0 SSW	7.5 SSE	7.5 ESE
27	22.0 WSW	12.0 WSW	9.0 SSW	7.5 ENE	8.5 ENE
28	16.0 WSW	29.0 SSE	20.0 SSE	5.0 ESE	13.0 ENE
29	25.5 SSW	27.5 SSW	--------	5.0 ESE	11.5 ENE
30	16.5 WSW	30.0 SSW	--------	10.0 SSE	11.5 ESE
31	14.0 WNW	20.5 SSW	--------	12.5 SSE	--------
Mean	18.0	21.4	14.5	12.3	8.7
S.D.	4.8	5.4	4.3	4.2	2.6

WINTER 1974/5

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	16.5 SSW	10.0 WSW	19.5 WSW	9.5 SSE	12.0 NNW
2	19.5 WSW	15.0 WSW	10.5 SSW	12.5 SSW	16.0 NNE
3	25.5 SSW	16.0 WNW	9.0 SSE	9.5 SSW	24.5 NNE
4	20.0 WNW	20.5 WNW	10.0 SSE	9.5 SSW	9.5 NNE
5	15.0 WNW	31.5 WSW	10.5 SSE	10.0 WSW	9.0 ENE
6	22.0 WNW	24.0 WNW	8.5 SSE	13.0 SSW	10.0 SSW
7	21.5 WNW	9.0 WNW	9.5 ENE	16.5 WSW	26.5 WNW
8	21.5 WSW	13.5 WNW	7.5 SSW	16.0 WSW	41.0 NNW
9	21.0 WSW	23.0 WSW	7.5 ESE	11.0 WSW	22.5 NNW
10	16.0 WNW	9.5 WSW	8.5 SSE	15.0 ENE	10.0 WSW
11	11.5 WNW	17.5 WSW	7.0 ESE	12.5 ENE	10.0 WSW
12	17.0 NNW	15.0 WSW	8.0 ESE	8.5 ENE	15.5 WSW
13	25.5 WSW	27.5 WSW	11.0 ENE	10.0 ENE	11.0 WSW
14	17.5 WSW	23.0 SSW	9.5 ESE	10.0 ENE	9.5 WSW
15	12.5 WSW	23.0 SSW	8.0 SSE	9.0 NNE	8.5 WSW
16	21.0 SSW	14.5 SSW	25.5 SSE	10.5 NNE	10.0 SSW
17	25.5 WNW	8.5 ENE	22.0 SSW	9.5 NNE	12.0 SSE
18	29.5 WNW	10.0 NNW	18.5 WSW	10.0 NNE	8.5 SSE
19	15.5 SSW	11.5 ENE	17.0 SSW	11.0 ENE	6.0 SSE
20	22.0 SSW	24.0 SSW	20.0 SSW	12.0 ENE	16.0 SSW
21	17.0 SSW	19.5 NNW	16.0 WSW	13.5 SSE	12.0 SSE
22	22.5 SSW	19.5 SSW	18.0 WSW	13.0 SSE	10.0 NNE
23	20.5 SSW	29.5 WSW	17.5 SSW	12.5 WSW	11.0 WNW
24	21.5 SSW	21.0 WNW	9.5 SSE	17.0 WNW	10.0 WNW
25	15.5 WSW	29.5 WNW	15.0 SSE	15.0 NNW	10.0 WNW
26	12.5 WSW	16.5 WSW	11.0 SSE	20.0 NNW	10.0 ESE
27	20.0 ESE	13.5 WSW	10.5 SSE	13.5 NNE	11.0 WNW
28	21.0 WSW	17.5 SSE	10.0 SSE	13.5 NNW	13.0 SSW
29	13.0 WNW	19.5 WNW	--------	13.5 NNW	17.0 SSW
30	17.0 WNW	25.0 WSW	--------	10.0 NNW	11.5 WSW
31	22.5 WSW	22.5 WSW	--------	11.0 NNW	--------
Mean	19.3	18.7	12.7	12.2	13.5
S.D.	4.2	6.4	5.1	2.7	6.9

WINTER 1975/6

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	15.5 WNW	14.5 WNW	8.0 ENE	18.0 WNW	8.0 WSW
2	23.0 NNE	24.0 SSW	10.0 ESE	8.0 WSW	8.0 NNE
3	17.0 WNW	23.0 NNW	10.0 ESE	14.0 SSW	13.0 WSW
4	13.0 WNW	19.0 WSW	12.0 ENE	19.0 SSE	11.5 SSW
5	13.5 WNW	16.5 WSW	10.0 ESE	20.5 SSE	18.5 WNW
6	8.0 WNW	12.0 WSW	13.0 ESE	16.5 SSE	19.0 WNW
7	13.0 NNW	10.5 WSW	11.0 SSE	13.0 ESE	8.0 NNW
8	14.5 WNW	10.0 WNW	12.0 SSE	5.5 ENE	8.5 WSW
9	14.0 WNW	19.0 WSW	25.5 WSW	11.0 SSW	13.5 WNW
10	8.0 WNW	21.5 WNW	15.5 WNW	14.0 SSE	20.5 WSW
11	14.5 WSW	13.0 WNW	15.5 WNW	14.5 SSE	13.0 SSW
12	13.0 WNW	12.0 WNW	18.0 WSW	11.0 ESE	9.0 NNW
13	12.5 WNW	12.0 WSW	11.5 NNE	8.5 ESE	20.5 SSE
14	14.0 WNW	19.0 WNW	14.0 SSW	13.5 SSE	11.5 NNW
15	14.5 WSW	14.0 WNW	8.0 WNW	17.0 ESE	7.0 NNW
16	10.4 NNW	8.0 WNW	11.0 SSE	13.5 ESE	7.5 WSW
17	8.5 NNE	15.0 WSW	9.0 SSE	10.5 SSE	13.0 WSW
18	14.0 WSW	23.5 WNW	9.0 SSE	5.5 ESE	6.5 SSE
19	8.5 WNW	28.0 WSW	9.0 SSE	11.0 SSE	5.0 ESE
20	14.0 WSW	23.0 WNW	10.5 SSE	19.0 SSE	5.0 ESE
21	20.0 WSW	19.0 NNW	16.0 SSE	17.0 SSE	7.5 ESE
22	16.0 WSW	14.0 WNW	14.5 SSE	9.5 SSE	9.0 ENE
23	15.0 WSW	14.5 WNW	18.0 SSW	10.0 SSE	6.5 NNE
24	16.5 WNW	17.5 NNE	16.5 WSW	18.0 SSW	9.0 NNE
25	13.5 WNW	11.0 WNW	23.5 WSW	11.5 WSW	6.5 NNE
26	16.0 WNW	10.5 NNW	11.0 WSW	16.5 WSW	5.0 NNW
27	20.5 WSW	16.5 SSE	10.5 WSW	21.5 WSW	6.0 NNE
28	15.0 WSW	24.5 ESE	11.0 SSW	22.0 WSW	6.5 ESE
29	16.0 WSW	21.5 ESE	16.0 SSW	19.0 WSW	8.0 WSW
30	26.5 WSW	12.5 ESE	--------	13.0 WNW	8.0 WNW
31	16.5 WNW	7.5 ESE	--------	15.5 WSW	-------
Mean	14.7	16.3	13.1	14.1	10.0
S.D.	4.0	5.3	4.2	4.4	4.5

WINTER 1976/7

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	11.5 WSW	12.0 NNW	11.5 SSW	14.0 SSE	18.0 SSW
2	10.0 WNW	11.5 NNW	15.5 SSW	14.0 SSW	23.5 WNW
3	10.0 WNW	10.0 WSW	25.5 SSW	25.5 WSW	21.5 NNW
4	10.0 WNW	25.0 SSW	13.5 WSW	24.0 WNW	13.0 WNW
5	11.0 WNW	24.0 SSW	13.0 SSE	27.0 WNW	14.5 WSW
6	20.5 SSE	18.0 WSW	8.5 SSW	11.5 WNW	22.5 WNW
7	9.5 SSW	15.5 WSW	15.0 NNW	15.0 SSE	22.0 NNW
8	10.0 WSW	12.5 WNW	10.0 NNW	19.0 SSW	12.0 NNW
9	13.0 WNW	19.0 WNW	15.0 SSE	17.5 SSW	7.0 NNW
10	15.0 WSW	16.0 NNE	27.5 ESE	18.0 SSE	9.5 WNW
11	10.0 WNW	11.0 NNE	25.0 ENE	20.0 SSE	8.5 WNW
12	8.5 WSW	10.0 NNE	11.0 ENE	14.0 SSW	14.0 WNW
13	9.5 SSW	12.5 ENE	11.0 ENE	10.0 SSW	22.0 WNW
14	8.0 SSW	21.0 ENE	10.0 SSE	17.5 SSE	18.5 WNW
15	9.0 SSW	24.0 ENE	12.5 SSE	16.0 SSE	9.0 NNW
16	9.0 SSE	11.0 NNE	16.0 SSE	19.0 SSE	14.0 WSW
17	14.5 ESE	7.5 WNW	18.5 SSE	21.0 SSW	12.0 NNW
18	13.5 SSE	10.0 SSE	22.5 ESE	20.0 SSE	10.0 NNE
19	9.0 ESE	17.5 SSE	17.5 ENE	11.5 ESE	11.0 SSE
20	14.0 ESE	16.0 SSE	10.0 NNE	11.0 NNE	9.0 WSW
21	14.5 ENE	23.0 SSE	9.0 ENE	11.5 NNE	15.5 WSW
22	10.5 ENE	18.5 SSE	15.5 ENE	8.0 ENE	9.0 NNE
23	11.5 ESE	11.5 SSW	12.5 ENE	12.0 ESE	20.5 WSW
24	8.5 ESE	11.5 SSW	15.0 ENE	8.5 ESE	11.0 NNE
25	14.0 NNW	17.0 SSE	11.5 ENE	11.5 NNW	15.0 SSE
26	11.5 WSW	17.5 NNW	7.5 NNW	10.0 NNE	14.0 SSW
27	17.0 WNW	12.0 ESE	12.5 ESE	15.0 NNE	12.5 WSW
28	13.0 NNE	7.5 NNE	10.0 NNW	17.0 NNE	16.0 SSE
29	11.0 SSW	6.0 WSW	--------	12.0 NNW	11.5 SSE
30	18.0 SSW	24.0 SSW	--------	21.0 SSW	9.5 WNW
31	20.5 WSW	12.5 SSW	--------	31.0 SSW	--------
Mean	12.1	15.0	14.4	16.2	14.2
S.D.	3.3	5.3	5.2	5.5	4.8

WINTER 1977/8

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	7.5 NNE	20.0 WSW	14.5 ESE	19.0 SSE	17.5 ESE
2	14.5 SSE	13.5 WSW	11.0 SSW	21.5 SSE	11.0 ESE
3	18.5 SSE	10.0 WNW	11.5 SSW	10.0 ESE	9.0 ESE
4	25.0 ESE	10.5 WSW	15.5 SSE	10.0 WNW	9.5 ESE
5	18.0 SSE	23.5 SSW	10.5 SSE	10.0 WNW	7.5 ENE
6	19.5 ESE	21.0 WSW	12.0 SSW	16.0 SSE	7.0 ENE
7	17.5 ESE	19.5 SSW	7.0 SSW	15.5 SSW	5.0 NNE
8	12.5 ESE	18.5 SSW	7.0 ESE	21.0 SSW	6.5 WNW
9	10.5 ENE	16.5 SSW	6.5 ESE	10.5 WSW	9.0 WNW
10	20.5 SSE	16.0 WSW	7.5 SSW	9.0 SSW	16.0 NNW
11	12.0 SSE	18.0 NNW	11.5 ESE	9.5 SSE	11.5 NNW
12	10.0 SSW	14.0 NNW	14.5 NNE	12.5 SSW	7.0 NNW
13	11.0 SSW	20.0 WSW	12.0 NNW	12.0 WSW	10.0 NNW
14	12.0 WSW	10.0 WNW	9.0 NNE	16.0 SSE	8.5 NNW
15	13.5 WSW	13.0 WSW	8.5 NNW	13.5 WNW	7.5 WNW
16	14.5 SSW	7.5 WNW	8.0 ENE	18.0 NNE	5.0 SSE
17	12.5 WSW	10.0 WNW	8.5 NNE	14.0 NNE	6.5 SSE
18	10.0 WSW	7.5 SSW	10.0 ESE	16.5 WSW	10.0 ESE
19	14.5 SSW	24.5 SSE	17.0 ESE	7.5 WSW	10.5 SSE
20	11.0 SSW	9.5 SSW	12.0 ESE	12.5 WSW	15.5 ESE
21	9.0 SSE	19.0 SSE	11.0 ESE	14.0 WNW	9.5 ESE
22	15.5 SSE	24.0 SSE	12.5 ESE	13.0 WSW	7.5 SSE
23	13.0 WSW	18.5 SSE	16.0 SSE	7.5 WSW	9.5 ESE
24	14.5 SSW	16.5 WNW	15.5 SSE	10.0 WSW	8.5 ESE
25	16.5 WNW	12.5 NNW	13.5 SSW	21.0 WSW	9.5 NNE
26	11.0 WSW	7.5 WNW	11.0 ESE	14.5 WSW	8.0 ENE
27	12.0 NNW	10.0 NNE	7.5 SSE	13.5 WSW	12.0 ENE
28	22.5 NNW	29.5 ENE	11.5 SSE	16.5 SSE	15.5 ENE
29	16.0 WNW	28.5 NNE	--------	20.5 SSW	10.0 ENE
30	25.0 NNW	13.0 NNE	--------	15.0 SSW	14.0 ENE
31	15.5 WNW	12.5 SSE	--------	11.0 ESE	--------
Mean	14.7	15.9	11.2	14.1	9.8
S.D.	4.4	6.0	2.9	4.0	3.2

WINTER 1978/9

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	11.0 SSE	12.5 SSW	11.5 WSW	13.0 WSW	7.5 WSW
2	22.5 SSE	10.5 NNW	9.5 SSW	28.5 WSW	5.0 WNW
3	17.5 SSE	15.0 SSW	17.5 WSW	20.0 WSW	6.5 ENE
4	27.0 SSE	10.0 SSW	16.5 WSW	27.0 WSW	9.0 NNE
5	15.0 SSE	8.5 WSW	7.5 WNW	26.5 WSW	5.5 ENE
6	17.5 SSE	24.5 SSW	7.5 SSW	19.5 SSW	6.5 ENE
7	29.0 ESE	17.5 WSW	10.0 ENE	11.0 WNW	10.5 ENE
8	29.0 ESE	14.5 WSW	15.0 NNW	22.5 SSW	18.0 ENE
9	12.5 ESE	14.0 SSW	15.0 ESE	20.0 WSW	9.0 ENE
10	19.0 ESE	14.5 NNE	15.5 ESE	13.0 WNW	11.5 ENE
11	16.0 SSE	19.0 NNW	16.5 ESE	22.5 SSE	11.0 SSE
12	15.0 SSE	11.0 WNW	24.0 ESE	31.0 WSW	13.0 SSE
13	12.0 SSE	5.0 WSW	27.0 ENE	10.0 WNW	19.5 ESE
14	11.0 ENE	9.5 ESE	22.5 ESE	11.0 NNE	5.0 SSW
15	12.0 ENE	16.0 SSW	13.0 ENE	16.0 NNE	5.0 NNE
16	8.0 NNW	9.0 WNW	18.0 ENE	15.5 NNE	9.5 NNW
17	9.0 NNW	13.0 NNE	9.5 SSE	16.5 ENE	9.0 SSE
18	13.5 SSW	10.0 ESE	15.0 SSE	14.0 ENE	6.5 SSW
19	17.5 SSW	22.0 ESE	13.0 SSE	13.5 SSW	14.0 SSW
20	7.5 SSW	24.0 ESE	18.5 SSE	20.0 SSW	9.0 WSW
21	16.5 ENE	14.0 ESE	16.5 SSE	21.0 NNW	17.5 WSW
22	12.0 ESE	8.0 SSE	9.0 WSW	18.5 NNW	11.5 WSW
23	8.0 ESE	6.0 NNW	16.5 WNW	14.5 WNW	12.0 ENE
24	15.0 ESE	10.0 WSW	5.0 SSW	17.0 SSE	16.0 NNW
25	28.5 ESE	12.5 SSW	15.5 SSW	15.5 NNE	16.5 NNE
26	12.5 ESE	9.0 WNW	25.5 SSW	11.0 NNW	14.0 NNW
27	13.5 ESE	11.5 NNW	15.0 SSW	8.5 NNW	11.0 WSW
28	18.0 ENE	23.0 SSE	11.5 SSW	20.0 NNW	12.0 NNW
29	29.0 ENE	18.0 SSE	--------	27.0 NNW	15.0 NNW
30	15.0 ESE	10.0 SSE	--------	11.5 NNW	23.0 NNW
31	19.0 ESE	25.5 SSW	--------	8.5 WNW	--------
MEAN	16.1	13.8	14.9	17.5	11.3
S.D.	6.6	5.5	5.3	6.0	4.6

WINTER 1979/80

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	20.5 WSW	12.5 WNW	11.0 ENE	16.0 WNW	9.5 SSW
2	16.5 WSW	15.0 WNW	9.0 ENE	11.5 WNW	21.0 WNW
3	17.0 WSW	20.5 SSE	11.5 ENE	10.0 WNW	13.0 WNW
4	14.5 SSW	23.0 SSW	10.0 ESE	11.0 SSW	9.5 WNW
5	14.0 WSW	25.5 WSW	21.5 ESE	14.0 SSE	9.0 SSW
6	13.5 WSW	19.0 WNW	17.0 ENE	11.0 SSE	5.0 SSW
7	27.5 ENE	7.5 ESE	18.0 ESE	15.5 ENE	11.5 WNW
8	15.0 ESE	10.5 SSE	19.0 SSE	11.5 NNE	19.0 NNW
9	5.0 ESE	18.0 SSE	10.5 ESE	9.0 WSW	21.0 NNW
10	5.0 SSE	10.0 SSE	13.0 WSW	8.0 SSW	14.5 WSW
11	7.5 SSE	12.0 SSE	12.5 WNW	19.5 SSW	12.5 WSW
12	17.5 SSE	8.0 SSW	17.0 WSW	12.0 WSW	16.0 SSE
13	24.0 SSE	12.0 SSW	13.5 SSW	9.0 WNW	20.0 SSE
14	11.5 SSE	11.5 NNW	22.5 SSW	8.0 ESE	17.5 SSW
15	9.0 WNW	12.0 NNW	9.5 SSW	9.5 SSE	7.5 SSE
16	17.0 SSE	7.0 WSW	15.0 ESE	15.0 SSE	6.0 SSE
17	31.5 WSW	12.0 WSW	14.5 SSW	20.5 ESE	9.5 WNW
18	13.5 WNW	15.5 SSW	14.5 SSW	25.0 ENE	16.5 WNW
19	15.5 NNW	17.0 SSE	13.0 SSW	17.0 ENE	25.0 WNW
20	9.5 NNW	16.5 SSE	12.0 SSE	10.0 SSW	23.5 WNW
21	14.5 SSW	21.5 ESE	24.5 SSE	10.0 NNE	22.5 NNW
22	18.0 SSW	22.5 ENE	17.0 SSE	13.0 ESE	10.0 WNW
23	14.5 SSW	12.5 ENE	17.5 SSW	11.0 SSE	11.0 WSW
24	10.0 SSW	10.0 ESE	10.0 SSW	20.5 ESE	6.0 WSW
25	20.5 SSW	7.5 WNW	8.5 SSW	22.5 ENE	7.5 WSW
26	20.5 SSE	8.0 NNE	6.5 SSW	28.0 ESE	5.0 SSW
27	12.5 SSW	12.5 SSE	10.0 SSW	13.0 ESE	5.0 WSW
28	10.5 WSW	12.5 ESE	11.5 WSW	10.0 ENE	8.5 ENE
29	6.5 WNW	11.5 ENE	18.0 WSW	14.0 NNW	7.0 WNW
30	10.0 WNW	14.5 ENE	--------	12.5 WNW	7.0 ENE
31	13.0 WNW	10.5 WNW	--------	17.0 SSE	--------
Mean	14.7	13.8	14.1	14.0	12.6
S.D.	6.0	4.9	4.4	5.0	6.1

WINTER 1980/1

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	19.5 WSW	27.0 NNW	24.5 WSW	24.5 ENE	9.0 SSE
2	15.5 NNW	21.5 WSW	25.5 WSW	22.5 ENE	8.0 WSW
3	13.0 NNW	25.0 NNW	16.5 WSW	10.0 NNE	5.0 ESE
4	14.0 NNW	22.0 NNW	20.5 WNW	7.5 WSW	5.0 SSE
5	16.5 WNW	9.0 WSW	17.0 WSW	7.5 ESE	6.5 ESE
6	15.0 NNE	11.0 NNE	27.5 WSW	20.0 ENE	5.0 ESE
7	9.0 NNW	14.0 WSW	22.0 SSW	17.5 WSW	5.5 ESE
8	18.0 WSW	23.0 WSW	29.0 WNW	17.5 WSW	13.5 WSW
9	22.5 WSW	18.0 WNW	5.0 WNW	15.0 WSW	14.5 WSW
10	20.5 SSW	21.5 NNE	13.0 NNW	15.0 ESE	12.0 SSW
11	13.0 WSW	13.0 WSW	11.0 SSW	18.0 WSW	15.0 SSE
12	16.0 WSW	23.0 NNW	24.5 SSW	12.5 WSW	8.5 ENE
13	13.5 SSW	18.5 WNW	13.5 SSW	8.5 ESE	12.5 ENE
14	21.0 WSW	23.0 NNW	16.0 SSW	7.0 NNW	14.0 ENE
15	12.0 WNW	22.5 NNW	14.5 WSW	10.0 NNW	10.5 ENE
16	15.0 WNW	14.5 ESE	10.0 WSW	13.0 NNW	8.0 ENE
17	18.5 SSW	29.5 ENE	21.5 SSW	11.0 WNW	9.5 ESE
18	18.0 WSW	12.5 SSE	18.0 SSE	30.0 WNW	7.5 ENE
19	14.5 SSE	27.5 WNW	14.0 ENE	27.5 WSW	12.0 ENE
20	9.5 SSE	11.0 WSW	10.0 SSE	10.5 WSW	8.0 NNW
21	8.5 SSE	19.5 WNW	18.0 SSE	15.0 NNW	8.5 NNW
22	15.5 WSW	12.5 WSW	13.5 NNE	15.5 WNW	10.0 NNE
23	19.0 WSW	18.0 WSW	11.5 ENE	16.5 SSE	8.0 SSE
24	11.0 WSW	27.5 WSW	7.5 NNE	10.5 SSW	20.5 ENE
25	16.0 WSW	14.0 WNW	17.5 SSE	19.0 SSW	18.0 ENE
26	17.0 WSW	14.0 WSW	17.0 ESE	16.0 WNW	10.0 NNE
27	10.0 WSW	14.5 WSW	21.5 ESE	16.5 SSE	11.0 NNE
28	22.5 WSW	16.0 WSW	23.0 ESE	33.0 SSE	14.5 NNW
29	23.5 WSW	23.0 WSW	--------	13.5 ENE	16.0 WNW
30	20.5 WSW	17.0 WSW	--------	5.0 SSW	13.0 WNW
31	27.5 WSW	23.0 WSW	--------	12.5 ESE	--------
Mean	16.3	18.9	17.3	15.4	10.6
S.D.	4.5	5.5	6.0	6.6	3.9

WINTER 1981/2

	DECEMBER	JANUARY	FEBRAURY	MARCH	APRIL
1	6.5 ESE	5.5 WSW	21.5 SSW	26.5 SSW	10.5 ESE
2	13.5 WSW	15.0 ENE	17.0 SSE	31.0 WSW	12.5 SSW
3	29.5 WSW	25.0 ENE	20.5 SSW	35.5 WSW	11.5 SSW
4	18.5 WNW	19.0 ENE	22.5 ESE	22.5 NNE	9.5 ENE
5	12.5 NNW	24.0 ENE	21.0 SSW	16.0 SSW	9.5 ENE
6	21.0 NNW	12.0 NNE	23.0 SSW	29.5 WSW	10.5 ENE
7	10.0 NNW	9.5 SSW	25.0 WSW	10.0 WSW	11.0 WSW
8	16.0 NNW	14.0 SSE	20.0 SSW	22.5 SSW	30.0 NNE
9	8.5 NNW	25.5 NNW	19.5 WSW	25.0 SSW	15.0 WSW
10	10.0 SSW	8.5 WSW	15.0 SSW	17.0 WNW	13.5 NNW
11	10.0 ENE	6.5 WSW	18.0 SSW	27.5 WSW	14.5 NNW
12	11.5 WSW	13.0 WSW	31.0 SSE	26.5 WSW	10.0 NNW
13	19.0 ESE	22.0 SSW	31.0 SSW	21.5 SSW	10.0 NNW
14	30.5 SSE	25.0 SSW	11.5 SSW	27.5 SSW	9.5 WSW
15	10.0 NNW	14.0 SSW	13.5 SSW	26.0 WSW	20.0 WSW
16	11.0 SSW	20.0 SSE	20.0 SSW	22.5 SSW	13.5 NNW
17	10.0 NNE	21.0 SSE	9.0 ENE	24.5 WSW	5.0 NNW
18	15.0 NNW	27.0 SSE	13.0 SSE	19.5 NNW	5.0 NNW
19	25.0 SSW	16.5 SSW	14.5 SSE	9.5 WNW	10.0 ESE
20	34.5 SSE	15.5 SSE	15.0 SSE	10.0 ENE	12.5 SSW
21	19.0 ESE	20.5 SSW	26.0 SSE	20.0 SSE	17.5 SSW
22	10.0 SSW	19.5 WNW	11.0 SSW	14.0 WSW	12.0 SSW
23	10.0 WSW	16.0 WNW	13.0 SSW	15.0 WSW	17.0 WNW
24	10.0 NNE	7.5 WSW	23.0 SSW	23.0 SSW	11.0 WNW
25	7.5 SSE	17.0 WSW	9.0 WNW	14.5 WSW	14.5 SSW
26	25.5 SSE	16.0 WSW	24.5 SSE	15.0 SSW	10.5 WNW
27	30.0 SSE	20.5 NNW	21.0 WSW	6.5 NNW	15.0 WSW
28	21.5 ESE	30.0 WSW	26.0 WSW	5.0 NNE	22.0 WNW
29	14.5 ENE	25.5 WSW	--------	14.0 NNE	28.5 WNW
30	14.0 ENE	32.0 WNW	--------	11.5 WSW	20.5 WNW
31	17.5 ESE	11.0 WSW	--------	5.0 NNE	--------
Mean	16.2	17.9	19.1	19.2	13.7
S.D.	7.5	6.8	6.0	7.9	5.7

WINTER 1982/3

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	21.0 SSW	14.5 WSW	20.5 NNE	20.0 WNW	11.5 SSE
2	19.5 SSW	21.5 SSW	25.5 ENE	10.0 SSW	15.0 NNW
3	16.0 SSW	22.5 WSW	10.0 WNW	12.0 SSE	10.5 NNE
4	17.0 SSW	25.0 WSW	19.5 SSW	22.0 SSE	15.0 NNW
5	25.0 SSW	22.0 SSW	18.0 WSW	21.0 WSW	6.5 ESE
6	6.5 WSW	30.0 WSW	24.5 NNW	21.0 WSW	4.5 ENE
7	27.0 SSE	24.5 WSW	28.0 NNE	30.5 WSW	5.0 WNW
8	18.0 SSW	33.0 WNW	20.0 NNW	18.5 WSW	7.0 WNW
9	13.5 WSW	25.0 WSW	11.5 NNE	20.5 WSW	10.0 WNW
10	17.0 WSW	25.5 WSW	12.5 NNW	21.5 WSW	10.5 NNE
11	9.5 SSW	33.5 SSW	19.5 WNW	12.0 WSW	14.5 NNE
12	7.5 NNE	20.0 SSW	13.5 NNE	11.5 SSE	16.0 NNE
13	5.5 NNW	19.0 NNW	5.5 WNW	17.0 SSW	15.0 WNW
14	15.5 SSW	16.5 NNW	5.0 WNW	22.5 SSW	17.0 WSW
15	18.5 WNW	23.5 WSW	4.5 SSE	17.0 SSW	16.5 WSW
16	22.0 WNW	29.5 WNW	6.5 ENE	13.0 WSW	13.5 WSW
17	24.5 WNW	27.5 WSW	7.0 SSE	17.0 WSW	21.5 WSW
18	14.0 NNW	33.0 WNW	8.0 ESE	13.0 WSW	6.5 SSE
19	21.5 WSW	27.5 WNW	4.5 WSW	8.0 WNW	12.0 NNE
20	27.5 SSW	26.5 WNW	9.5 NNE	7.5 WNW	10.5 NNW
21	31.0 SSW	23.5 WSW	12.5 ESE	23.5 SSW	18.5 NNE
22	25.0 NNW	26.0 WSW	10.5 SSE	23.0 SSW	13.5 ENE
23	19.5 WSW	20.5 WSW	13.5 NNW	23.5 WSW	10.5 ENE
24	15.0 WNW	15.0 SSW	12.5 SSW	20.5 NNW	17.0 ENE
25	29.0 WSW	29.5 SSW	10.5 SSE	21.5 NNW	17.0 ENE
26	18.0 SSW	25.5 WSW	11.5 SSE	16.5 WSW	11.0 SSE
27	22.0 WNW	24.5 WSW	21.5 SSW	18.0 NNW	10.0 ENE
28	17.0 WSW	25.0 WSW	13.0 WNW	10.0 NNE	10.5 ENE
29	18.0 WSW	26.5 WSW	--------	14.0 WNW	8.0 ENE
30	12.0 SSW	23.5 WSW	--------	19.0 SSW	12.0 NNE
31	22.5 SSW	19.5 SSE	--------	14.5 WSW	--------
Mean	18.6	24.5	13.5	17.4	12.2
S.D.	6.3	4.8	6.5	5.3	4.1

WINTER 1983/4

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	16.5 SSW	27.0 WSW	17.0 SSW	16.0 WSW	7.5 ENE
2	22.0 SSW	26.0 WNW	15.0 WSW	24.5 NNW	10.0 ESE
3	15.0 SSW	38.5 WNW	17.0 WNW	17.0 SSW	8.5 SSE
4	27.5 SSW	26.5 WSW	28.5 SSW	21.5 NNW	14.0 ESE
5	20.0 SSW	26.0 NNW	18.5 WSW	17.5 WSW	10.0 SSE
6	19.0 WSW	18.5 SSW	28.0 WNW	12.0 WNW	10.0 ESE
7	18.5 SSW	24.5 WSW	32.0 WNW	10.5 WNW	6.5 NNW
8	12.5 WSW	26.5 NNW	30.5 WNW	10.0 WNW	10.5 NNW
9	24.0 ESE	26.5 NNW	12.5 WSW	5.0 WSW	6.0 NNW
10	15.0 NNW	18.5 WSW	20.0 WNW	6.5 WSW	14.5 WSW
11	17.5 NNW	22.5 SSE	17.5 SSW	9.5 NNW	21.0 WSW
12	9.5 SSW	23.5 WNW	14.0 SSW	8.0 ESE	25.5 WSW
13	18.0 SSW	33.0 WNW	19.0 SSW	12.0 ENE	19.0 WSW
14	24.5 SSW	28.0 SSE	19.0 SSW	13.0 ENE	13.0 WSW
15	20.0 WSW	23.5 WSW	17.5 SSW	12.0 ENE	17.5 WNW
16	16.0 SSE	23.5 SSE	16.5 SSW	13.5 ESE	15.5 WSW
17	19.0 ESE	15.0 WNW	22.5 SSW	7.5 ESE	12.5 WSW
18	19.5 ESE	20.5 ENE	19.0 SSW	7.0 WSW	15.0 SSW
19	21.5 ESE	11.5 WNW	22.0 ESE	12.0 SSW	21.5 SSE
20	20.5 ENE	11.0 ESE	27.5 SSE	9.0 SSE	23.5 SSW
21	18.5 ENE	18.0 SSE	20.5 ESE	12.0 SSE	13.0 WSW
22	14.5 ENE	22.5 SSE	18.5 SSE	12.5 ESE	18.5 SSW
23	15.0 ENE	30.5 SSE	10.0 ESE	21.5 ESE	6.5 SSW
24	18.0 ESE	10.0 SSE	8.5 SSE	27.0 ESE	6.5 WSW
25	19.5 WSW	10.5 SSE	12.5 SSW	25.0 ESE	7.0 ESE
26	20.5 SSW	16.5 SSE	6.5 SSW	28.5 ESE	5.0 ENE
27	21.0 WNW	12.0 ESE	5.0 ENE	20.5 ESE	6.0 ENE
28	25.5 SSW	23.5 NNE	14.5 SSW	20.5 ENE	9.0 SSE
29	21.5 WSW	10.0 SSE	6.5 WSW	13.0 ENE	6.5 SSE
30	19.5 WSW	19.5 SSE	--------	11.5 ENE	15.5 ENE
31	29.0 WSW	14.0 SSW	--------	11.5 NNE	--------
Mean	19.3	21.2	17.8	14.4	12.5
S.D.	4.1	7.1	6.9	6.2	5.7

WINTER 1984/5

	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL
1	21.0 SSW	23.5 WNW	28.0 WSW	11.5 ESE	12.0 ENE
2	19.0 SSW	17.0 WNW	22.0 NNE	12.0 SSE	10.5 SSW
3	13.5 SSE	12.0 NNW	25.5 WSW	16.0 ESE	25.5 WNW
4	14.5 SSE	7.5 NNE	12.5 WSW	16.5 WSW	19.5 SSE
5	9.0 SSW	11.0 NNW	9.5 SSW	27.0 ENE	14.0 SSE
6	16.0 SSW	13.0 NNE	8.0 ESE	22.5 SSW	10.0 ESE
7	19.5 SSW	12.5 NNW	13.5 ESE	12.0 SSW	13.5 ESE
8	24.0 SSW	13.5 NNE	18.5 ESE	23.0 SSW	13.5 ENE
9	19.5 SSW	10.0 NNW	26.0 ESE	16.5 WSW	10.0 ENE
10	19.0 WSW	7.5 NNW	23.0 ESE	16.5 SSW	13.5 ENE
11	20.0 WSW	12.5 SSW	18.0 ESE	20.5 WSW	10.5 WNW
12	13.0 SSW	13.5 SSW	13.5 SSE	15.0 SSW	22.0 SSW
13	14.5 ESE	13.0 SSW	11.0 NNW	22.0 WSW	16.0 WSW
14	24.0 SSW	9.5 WSW	13.0 ENE	13.5 WNW	17.0 SSW
15	16.0 NNE	6.5 SSW	9.5 ENE	10.0 NNW	11.5 NNW
16	12.0 SSE	12.0 ESE	5.0 ENE	11.5 WSW	15.0 WNW
17	23.0 SSE	19.0 ESE	13.5 SSW	8.5 WNW	13.0 WSW
18	16.5 SSE	15.0 ESE	22.5 SSW	13.0 SSE	11.5 SSW
19	27.5 WSW	10.5 ESE	31.0 SSW	15.5 SSE	22.5 WSW
20	21.5 SSW	5.5 ESE	16.5 SSW	18.0 SSE	22.0 SSW
21	29.0 WSW	18.5 ESE	14.5 SSW	19.0 SSE	21.5 NNW
22	18.5 WNW	29.0 WNW	19.5 SSW	19.0 SSE	15.0 NNE
23	22.0 SSW	33.5 WNW	17.5 SSW	20.0 ESE	5.0 ENE
24	17.0 SSW	18.0 NNW	24.0 SSW	9.0 ENE	24.0 ENE
25	25.5 SSW	21.0 NNW	23.5 WSW	9.5 ENE	14.5 WNW
26	11.5 SSW	10.0 ENE	11.0 SSW	8.0 ENE	15.5 NNW
27	15.0 SSW	15.5 NNE	13.5 SSW	15.5 NNW	17.5 NNW
28	10.0 SSW	9.5 WSW	12.5 SSW	15.0 NNE	16.0 NNW
29	22.5 SSW	29.0 ENE	--------	10.5 WNW	18.5 NNW
30	17.5 SSE	20.0 SSW	--------	5.0 WNW	9.5 WSW
31	20.5 WNW	30.0 WNW	--------	16.5 WSW	--------
Mean	18.5	15.4	17.0	15.1	15.3
S.D.	4.9	7.2	6.5	5.0	4.8

APPENDIX 3: MONTHLY SUMMARY OF WINTER WEATHER FROM 1954/5 TO 1984/5.

The values for the amount of precipitation, the percentage falling as snow and the minimum and maximum temperatures are the average between the values at Braemar and at one of the stations in the Spey Valley (Achnagoichan, Glenmore Lodge and Lagganlia). See Chapter 4 for full details. Although Chapter 4 is concerned only with the winters 1954/5 to 1983/4, data were required for 1984/5 for use in Chapters 7 and 8.

A amount of precipitation (mm)
B mean minimum daily air temperature (^{0}C)
C mean maximum daily air temperature (^{0}C)
D percentage of precipitation falling as snow
E mean geostrophic wind speed (m/s)
F amount of snowdrift

		A	B	C	D	E	F
1954/5	DECEMBER	159.8	0.6	6.1	60.8	20.5	123
	JANUARY	36.8	-3.8	2.0	48.3	14.6	64
	FEBRUARY	92.7	-6.3	0.6	100.0	14.1	169
	MARCH	78.7	-2.1	3.8	96.3	13.5	69
	APRIL	20.8	1.6	12.2	0.0	11.2	0
1955/6	DECEMBER	145.9	-0.7	4.4	67.2	17.5	150
	JANUARY	83.4	-2.6	1.7	96.4	16.0	112
	FEBRUARY	79.4	-3.4	0.7	73.7	11.0	58
	MARCH	49.5	0.7	5.5	28.9	16.0	27
	APRIL	49.8	0.8	7.0	27.5	9.6	14
1956/7	DECEMBER	135.6	1.7	6.6	45.4	18.8	80
	JANUARY	88.5	-0.5	6.1	50.1	17.8	59
	FEBRUARY	79.0	-2.7	4.1	65.3	14.1	72
	MARCH	75.2	2.6	9.6	16.1	13.8	9
	APRIL	33.4	1.3	10.3	24.0	10.4	12
1957/8	DECEMBER	85.6	-1.2	5.5	81.7	18.4	98
	JANUARY	86.8	-3.7	3.8	87.6	15.5	88
	FEBRUARY	91.0	-2.9	3.7	76.4	15.5	84
	MARCH	69.2	-3.7	3.0	95.0	13.9	80
	APRIL	41.1	1.1	8.3	73.8	12.0	36

		A	B	C	D	E	F
1958/9	DECEMBER	113.5	-2.1	4.0	100.0	14.7	126
	JANUARY	67.8	-5.9	1.7	100.0	14.7	103
	FEBRUARY	14.2	-2.9	6.8	9.9	14.6	5
	MARCH	46.5	0.3	8.3	16.8	13.3	6
	APRIL	68.9	2.0	8.9	24.5	12.0	19
1959/60	DECEMBER	145.2	-0.6	3.2	87.3	17.1	
	JANUARY	109.7	-2.2	4.0	96.4	13.5	126
	FEBRUARY	83.9	-5.2	3.7	64.7	14.5	73
	MARCH	21.3	0.0	6.9	82.2	13.7	18
	APRIL	75.5	2.4	11.0	0.0	13.5	0
1960/1	DECEMBER	76.2	-3.3	3.5	57.5	14.6	58
	JANUARY	83.8	-2.6	3.5	95.1	15.4	117
	FEBRUARY	55.6	-1.3	6.8	50.4	15.8	45
	MARCH	33.0	2.4	10.2	29.1	16.9	15
	APRIL	39.1	2.1	10.4	30.2	11.4	8
1961/2	DECEMBER	108.4	-5.2	2.2	78.9	13.6	79
	JANUARY	147.4	-1.7	5.0	92.1	18.7	204
	FEBRUARY	91.3	-1.7	5.6	92.8	18.4	101
	MARCH	89.6	-4.1	3.0	100.0	11.5	76
	APRIL	35.4	-0.6	9.3	94.9	12.6	34
1962/3	DECEMBER	138.6	-2.0	4.3	74.3	16.1	124
	JANUARY	60.9	-7.7	-0.3	100.0	13.1	70
	FEBRUARY	30.2	-7.9	1.2	100.0	13.1	54
	MARCH	80.6	-0.7	7.6	21.0	15.7	23
	APRIL	63.1	1.5	9.8	34.4	14.7	29
1963/4	DECEMBER	34.9	-1.0	4.0	61.0	14.8	35
	JANUARY	28.2	-1.0	6.0	27.3	14.2	10
	FEBRUARY	28.0	-1.2	5.4	68.9	15.6	28
	MARCH	56.0	-0.7	5.1	81.8	13.9	73
	APRIL	61.2	2.4	10.1	18.6	12.0	7
1964/5	DECEMBER	96.5	-2.7	4.1	63.7	14.6	84
	JANUARY	82.2	-2.9	3.1	98.4	13.5	104
	FEBRUARY	40.2	-1.6	4.2	67.7	12.3	50
	MARCH	30.1	-2.2	6.4	42.2	13.4	37
	APRIL	63.5	0.1	9.6	45.8	11.8	32
1965/6	DECEMBER	73.8	-3.2	2.9	95.1	14.6	86
	JANUARY	35.4	-2.5	3.2	49.5	12.4	22
	FEBRUARY	67.4	-2.7	3.6	36.5	13.7	43
	MARCH	58.0	1.0	7.5	66.6	17.0	68
	APRIL	37.1	-0.8	6.8	50.1	13.5	26

		A	B	C	D	E	F
1966/7	DECEMBER	127.1	-1.6	4.3	79.9	17.7	146
	JANUARY	78.0	0.0	4.6	83.2	15.6	73
	FEBRUARY	93.0	0.3	5.6	86.5	16.3	130
	MARCH	118.5	0.3	6.6	72.2	19.3	103
	APRIL	97.0	0.9	9.8	31.2	13.4	48
1967/8	DECEMBER	56.5	-0.5	5.1	69.4	14.4	45
	JANUARY	71.8	-1.5	4.5	92.3	14.2	65
	FEBRUARY	49.7	-5.8	2.1	100.0	11.0	58
	MARCH	75.0	0.2	6.8	53.3	13.9	58
	APRIL	67.6	0.9	10.3	48.8	10.9	41
1968/9	DECEMBER	79.2	-1.8	4.0	97.3	14.6	76
	JANUARY	113.7	-1.1	5.6	94.8	15.1	135
	FEBRUARY	69.8	-6.0	1.2	100.0	14.1	81
	MARCH	31.6	-3.9	4.1	85.4	13.1	39
	APRIL	67.1	-0.6	8.4	74.2	12.3	54
1969/70	DECEMBER	48.3	-1.8	4.1	78.7	14.4	55
	JANUARY	61.2	-2.4	3.6	81.0	14.6	69
	FEBRUARY	101.2	-5.2	2.6	100.0	13.9	113
	MARCH	87.1	-3.0	4.4	91.6	14.8	98
	APRIL	77.7	-1.2	6.7	77.2	12.3	70
1970/1	DECEMBER	63.2	-0.4	4.9	78.8	12.6	52
	JANUARY	85.1	-0.5	5.1	56.8	12.4	52
	FEBRUARY	25.3	-1.2	6.0	61.3	12.2	19
	MARCH	46.9	-0.6	7.0	59.3	11.2	32
	APRIL	40.0	0.2	10.4	21.3	9.8	11
1971/2	DECEMBER	63.0	2.7	8.0	42.5	17.4	41
	JANUARY	140.0	-1.3	3.7	89.5	16.1	161
	FEBRUARY	67.7	-1.4	4.4	100.0	13.2	81
	MARCH	54.4	-0.9	7.6	84.0	13.3	75
	APRIL	56.0	1.7	10.1	4.1	12.3	4
1972/3	DECEMBER	83.9	-0.5	6.1	92.1	17.5	115
	JANUARY	50.5	-0.9	5.0	85.5	16.1	67
	FEBRUARY	43.6	-3.2	4.8	86.7	15.9	64
	MARCH	26.8	-0.8	8.9	54.1	14.7	16
	APRIL	68.0	0.4	7.4	75.9	14.0	59
1973/4	DECEMBER	105.9	-1.6	4.8	90.2	17.4	133
	JANUARY	234.0	0.1	5.2	81.9	21.4	263
	FEBRUARY	44.6	-0.2	6.0	90.1	14.5	50
	MARCH	58.7	-1.3	7.2	94.0	12.3	70
	APRIL	15.5	-1.4	13.8	0.0	8.7	0

		A	B	C	D	E	F
1974/5	DECEMBER	120.4	1.9	7.2	50.4	19.3	79
	JANUARY	163.9	-0.9	6.3	63.1	18.7	136
	FEBRUARY	29.1	-2.5	6.2	98.6	12.7	32
	MARCH	31.1	-1.9	5.9	73.6	12.2	36
	APRIL	78.9	1.7	9.3	47.3	13.5	64
1975/6	DECEMBER	40.1	-0.5	7.3	0.0	14.7	0
	JANUARY	110.9	-0.6	5.5	88.5	16.3	138
	FEBRUARY	27.6	-1.3	5.7	74.3	13.1	35
	MARCH	56.7	-0.6	5.9	90.8	14.1	70
	APRIL	21.0	1.6	10.4	77.6	9.9	19
1976/7	DECEMBER	38.8	-3.7	2.0	100.0	12.1	58
	JANUARY	73.9	-3.8	2.7	93.6	15.0	85
	FEBRUARY	51.4	-3.2	3.6	100.0	14.4	71
	MARCH	90.2	0.9	7.3	45.9	16.2	60
	APRIL	72.7	0.5	7.7	36.9	14.2	45
1977/8	DECEMBER	55.0	-0.1	6.3	46.4	14.7	40
	JANUARY	117.6	-3.8	3.2	98.3	15.9	155
	FEBRUARY	39.8	-7.5	1.9	99.2	11.2	45
	MARCH	109.4	0.4	7.1	55.8	14.1	64
	APRIL	32.4	-0.2	8.0	94.1	9.8	34
1978/9	DECEMBER	128.2	-0.4	4.0	78.2	16.4	142
	JANUARY	68.4	-7.9	1.4	100.0	13.8	98
	FEBRUARY	17.8	-6.4	1.9	100.0	14.9	28
	MARCH	123.8	-2.0	3.8	91.8	17.5	162
	APRIL	60.2	1.3	8.1	60.6	11.3	32
1979/80	DECEMBER	127.9	-0.9	4.6	79.4	14.7	131
	JANUARY	94.7	-3.0	2.6	100.0	13.8	116
	FEBRUARY	38.8	-1.3	5.7	54.4	14.1	20
	MARCH	70.1	-2.1	5.3	76.8	13.9	68
	APRIL	9.4	1.6	11.3	0.0	12.6	0
1980/1	DECEMBER	78.4	0.4	5.8	80.6	16.3	80
	JANUARY	84.0	-1.6	5.2	81.4	18.9	98
	FEBRUARY	43.4	-1.4	4.4	61.1	17.3	39
	MARCH	61.6	-0.1	7.3	50.6	15.4	47
	APRIL	11.8	-1.2	11.4	42.4	10.6	2
1981/2	DECEMBER	48.1	-7.2	1.0	91.7	16.2	66
	JANUARY	75.9	-4.8	2.7	91.4	17.9	109
	FEBRUARY	58.6	-0.6	6.3	98.3	19.1	93
	MARCH	101.8	-0.2	6.5	98.7	19.2	176
	APRIL	27.2	2.1	10.7	52.9	13.7	13

		A	B	C	D	E	F
1982/3	DECEMBER	112.9	-2.3	4.2	95.3	18.6	136
	JANUARY	152.2	0.7	5.9	63.9	24.5	173
	FEBRUARY	67.0	-5.0	2.4	100.0	13.5	95
	MARCH	60.6	1.4	7.1	71.3	17.4	65
	APRIL	47.7	-0.6	7.4	52.8	12.2	29
1983/4	DECEMBER	149.4	0.3	6.6	48.3	19.3	97
	JANUARY	173.8	-5.8	1.7	100.0	21.2	258
	FEBRUARY	73.7	-0.6	4.7	99.5	17.8	122
	MARCH	105.8	-1.0	5.2	99.4	14.4	148
	APRIL	10.9	0.3	11.5	92.7	12.5	18
1984/5	DECEMBER	74.5	0.1	6.1	53.8	18.5	56
	JANUARY	90.9	-4.8	1.3	96.1	15.4	113
	FEBRUARY	19.2	-3.9	5.0	88.0	17.0	21
	MARCH	56.5	-1.7	5.2	87.3	15.1	54
	APRIL	60.5	1.2	9.5	34.0	15.3	33

APPENDIX 4: WINTER WEATHER BETWEEN 1954/5 TO 1984/5.

This appendix lists the type of weather on each day for the 30 winters from 1954/5 to 1984/5. The wind data required for the calculation of snowdrift are listed in Appendix 2. The data are analysed in sections 4.3 and 4.4. Methods for the calculation of snowdrift and wind-drift are described in sections 4.5 and 4.6 respectively.

1. Snowdrift. On days with snowdrift there are three figures. The left-hand one represents the amount of precipitation (see below), the middle one represents the wind speed (see below) and the right-hand one is the value of snowdrift (equal to the precipitation multiplied by the wind speed). The classes are:

Precipitation (mm)	Class	Wind speed (m/s)
1.0 - 4.9	1	0.0 - 4.4
5.0 - 9.9	2	4.5 - 8.9
10.0 - 14.9	3	9.0 - 13.4
....	.	....
....	.	....
45.0 - 49.9	10	40.5 - 44.9

On the 7.12.54, for example, the amount of precipitation was classed as 4 (i.e., 15.0 - 19.9mm) and the wind speed as 3 (i.e., 9.0 - 13.4m/s), giving a value of snowdrift of 12. Snowdrift values are analysed by month and wind direction in the summary of each winter. The total value for each winter for each direction are those used in Appendix 5 to calculate the amount of snowdrift for each site (see also Table 4.9).

A value of snowdrift with an "!" beside it is of storm proportions, and were defined and examined in section 4.5.2.

2. --*-- day with wind-drift.

3. -*- day with a mean max. temperature of below 2 C, but with precipitation of less than 1.0mm and no wind-drift.

4. * day with a mean max. temperature of above 0 C but with rainfall of less than 1.0mm.

5. RAIN day with a mean max. temperature of above 0 C and with rainfall of more than 1.0mm.

WINTER: 1954/5

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	RAIN		-*-		1 4	4	1 6	6	*	
2	RAIN		-*-		2 4	8	--*--		--*--	
3	RAIN		-*-		--*--		1 5	5	*	
4	RAIN		1 5	5	--*--		--*--		*	
5	-*-		--*--		-*-		1 5	5	RAIN	
6	-*-		--*--		-*-		1 4	4	*	
7	4 3	12	-*-		1 3	3	1 2	2	RAIN	
8	3 5	15!	-*-		2 4	8	2 3	6	RAIN	
9	3 7	21!	1 3	3	1 3	3	1 2	2	RAIN	
10	2 3	6	1 2	2	1 5	5	--*--		*	
11	1 3	3	--*--		2 4	8	--*--		*	
12	1 5	5	4 8	32!	2 5	10	-*-		*	
13	--*--		--*--		1 3	3	-*-		*	
14	1 5	5	2 3	6	1 4	4	RAIN		*	
15	--*--		--*--		2 3	6	RAIN		*	
16	--*--		--*--		2 5	10	1 3	3	*	
17	RAIN		1 4	4	8 6	48!	1 5	5	*	
18	*		2 3	6	1 3	3	1 4	4	*	
19	RAIN		--*--		--*--		1 3	3	*	
20	1 6	6	--*--		1 2	2	2 5	10	*	
21	2 8	16!	-*-		2 2	4	1 4	4	*	
22	2 5	10	1 3	3	--*--		--*--		*	
23	2 8	16!	--*--		--*--		1 5	5	*	
24	1 4	4	*		1 3	3	1 3	3	*	
25	1 4	4	RAIN		--*--		--*--		RAIN	
26	RAIN		-*-		--*--		--*--		RAIN	
27	*		1 3	3	1 4	4	1 2	2	RAIN	
28	RAIN		RAIN		5 6	30!	--*--		*	
29	RAIN		RAIN		-----		--*--		*	
30	*		*		-----		-*-		RAIN	
31	*		*		-----		-*-		-----	
TOTAL		123		64		166		69		0

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	36	0	8	9	6	64	0	123	29.1
JANUARY	0	5	0	0	3	3	10	37	64	15.2
FEBRUARY	20	3	8	8	30	3	0	94	166	39.3
MARCH	14	2	8	4	11	10	0	20	69	16.4
APRIL	0	0	0	0	0	0	0	0	0	0.0
TOTAL	34	46	16	20	53	22	80	151	422	
%	8.1	10.9	3.8	4.7	12.6	5.2	19.0	35.8		

WINTER 1955/6

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	*		RAIN		--*--		RAIN		*	
2	RAIN		*		-*-		1 7	7	RAIN	
3	1 7	7	*		1 4	4	1 5	5	RAIN	
4	*		*		4 3	12	--*--		2 3	6
5	RAIN		*		RAIN		1 3	3	-*-	
6	RAIN		*		RAIN		1 3	3	1 2	2
7	1 3	3	2 5	10	RAIN		-*-		*	
8	--*--		1 4	4	RAIN		*		RAIN	
9	2 4	8	1 4	4	-*-		*		RAIN	
10	1 5	5	2 4	8	1 2	2	*		-*-	
11	--*--		1 3	3	1 3	3	*		*	
12	-*-		--*--		2 4	8	*		*	
13	2 5	10	-*-		2 5	10	*		*	
14	4 7	28!	-*-		-*-		*		RAIN	
15	1 2	2	1 3	3	1 4	4	1 4	4	-*-	
16	1 3	3	--*--		-*-		--*--		1 3	3
17	1 3	3	2 6	12	-*-		--*--		RAIN	
18	--*--		--*--		1 2	2	-*-		*	
19	-*-		2 4	8	2 2	4	-*-		*	
20	-*-		2 6	12	1 3	3	1 5	5	*	
21	--*--		3 7	21!	1 3	3	RAIN		*	
22	3 4	12	--*--		--*--		RAIN		*	
23	2 8	16!	1 3	3	-*-		*		*	
24	*		--*--		-*-		RAIN		-*-	
25	RAIN		-*-		-*-		*		RAIN	
26	RAIN		1 4	4	-*-		*		RAIN	
27	2 7	14	1 3	3	1 3	3	*		1 3	3
28	3 7	21!	2 5	10	RAIN		*		RAIN	
29	2 7	14	--*--		RAIN		*		*	
30	1 3	3	1 3	3	-----		*		*	
31	RAIN		1 4	4	-----		*		-----	
TOTAL		150		112		58		27		14

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	3	43	41	0	45	17	0	149	41.4
JANUARY	0	0	4	20	3	41	44	0	112	31.1
FEBRUARY	3	14	0	0	16	3	0	22	58	16.1
MARCH	0	0	5	4	0	0	18	0	27	7.5
APRIL	3	0	0	0	0	0	0	11	14	3.9
TOTAL	6	17	52	65	19	89	79	33	360	
%	1.7	4.7	14.4	18.1	5.3	24.7	21.9	9.2		

WINTER: 1956/7

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	RAIN		1 4	4	2 5	10	*		*	
2	RAIN		--*--		1 5	5	*		*	
3	*		1 4	4	3 7	21!	RAIN		*	
4	RAIN		RAIN		RAIN		-*-		RAIN	
5	RAIN		RAIN		RAIN		-*-		*	
6	*		--*--		1 3	3	*		-*-	
7	*		*		1 4	4	*		-*-	
8	*		RAIN		RAIN		RAIN		-*-	
9	*		1 7	7	-*-		*		1 2	2
10	1 6	6	--*--		RAIN		*		1 3	3
11	1 3	3	--*--		1 3	3	*		1 4	4
12	2 6	12	1 5	5	-*-		*		--*--	
13	1 8	8	--*--		1 4	4	*		*	
14	RAIN		1 2	2	1 3	3	RAIN		*	
15	RAIN		-*-		-*-		RAIN		RAIN	
16	--*--		-*-		1 3	3	RAIN		*	
17	--*--		-*-		1 3	3	RAIN		1 3	3
18	*		-*-		--*--		RAIN		*	
19	*		--*--		-*-		RAIN		*	
20	*		RAIN		-*-		--*--		RAIN	
21	*		*		-*-		-*-		RAIN	
22	RAIN		1 3	3	-*-		*		*	
23	--*--		1 5	5	1 5	5	RAIN		*	
24	1 5	5	--*--		1 5	5	*		RAIN	
25	1 5	5	2 4	8	1 3	3	*		*	
26	1 4	4	1 5	5	-*-		RAIN		*	
27	1 4	4	1 6	6	-*-		3 3	9	RAIN	
28	2 7	14	RAIN		--*--		*		RAIN	
29	1 3	3	-*-		-----		*		*	
30	4 4	16!	2 5	10	-----		*		*	
31	RAIN		RAIN		-----		*		-----	
TOTAL		80		59		72		9		12

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	0	44	7	21	8	0	0	80	34.5
JANUARY	2	0	4	19	0	29	5	0	59	25.4
FEBRUARY	3	7	10	25	8	10	9	0	72	31.0
MARCH	0	0	0	0	0	0	9	0	9	3.9
APRIL	0	0	0	0	3	0	0	9	12	5.2
TOTAL	5	7	58	51	32	47	23	9	232	
%	2.2	3.0	25.0	22.0	13.8	20.3	9.9	3.9		

WINTER: 1957/8

	DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
1	*			-*-			*			*			*		
2	-*-			-*-			*			*			*		
3	*			-*-			*			*			2	3	6
4	*			2	5	10	RAIN			RAIN			2	4	8
5	*			--*--			1	5	5	1	4	4	2	4	8
6	1	4	4	1	3	3	1	4	4	3	5	15	-*-		
7	5	4	20!	-*-			3	2	6	3	6	18!	1	3	3
8	2	4	8	3	3	9	3	6	18!	2	4	8	1	3	3
9	--*--			2	6	12	1	3	3	3	3	9	--*--		
10	2	5	10	1	5	5	2	4	8	1	3	3	-*-		
11	5	7	35!	--*--			RAIN			-*-			*		
12	1	5	5	--*--			-*-			1	3	3	*		
13	--*--			*			*			1	3	3	*		
14	-*-			*			*			--*--			*		
15	--*--			*			RAIN			-*-			-*-		
16	1	5	5	*			-*-			*			1	3	3
17	--*--			1	5	5	1	4	4	-*-			RAIN		
18	*			2	4	8	--*--			-*-			RAIN		
19	RAIN			3	4	12	2	5	10	-*-			*		
20	RAIN			--*--			RAIN			-*-			*		
21	RAIN			1	3	3	-*-			-*-			*		
22	*			1	4	4	1	3	3	-*-			RAIN		
23	-*-			1	3	3	1	3	3	-*-			RAIN		
24	*			1	2	2	2	5	10	-*-			*		
25	-*-			2	6	12	1	4	4	-*-			1	4	4
26	*			*			2	3	6	-*-			1	4	4
27	*			RAIN			RAIN			--*--			RAIN		
28	1	6	6	RAIN			*			1	5	5	*		
29	1	5	5	*			-----			3	4	12	*		
30	--*--			*			-----			RAIN			*		
31	--*--			*			-----			--*--			-----		
TOTAL			98			88			84			80			36

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMEBER	0	5	35	10	4	25	19	0	98	25.4
JANUARY	0	0	0	22	8	29	26	3	88	22.8
FEBRUARY	0	14	29	0	0	0	25	16	84	21.8
MARCH	20	17	3	0	0	4	33	3	80	20.7
APRIL	0	16	3	0	4	4	0	9	36	9.3
TOTAL	20	52	70	32	16	62	103	31	386	
%	5.2	13.5	18.1	8.3	4.1	16.1	26.7	8.0		

WINTER: 1958/9

	DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
1	1	3	3	3	4	12	-*-			*			*		
2	--*--			1	7	7	-*-			1	3	3	*		
3	--*--			1	4	4	-*-			*			*		
4	--*--			1	6	6	-*-			1	3	3	RAIN		
5	-*-			--*--			-*-			RAIN			*		
6	-*-			-*-			-*-			RAIN			1	4	4
7	1	4	4	1	3	3	-*-			-*-			2	5	10
8	1	4	4	2	4	8	*			-*-			1	3	3
9	--*--			1	4	4	*			-*-			1	2	2
10	-*-			1	4	4	*			-*-			RAIN		
11	2	4	8	2	6	12	-*-			RAIN			RAIN		
12	2	5	10	2	5	10	-*-			*			*		
13	--*--			-*-			*			*			RAIN		
14	6	3	18!	-*-			*			RAIN			RAIN		
15	--*--			-*-			RAIN			*			*		
16	1	4	4	-*-			*			*			*		
17	--*--			1	3	3	*			*			RAIN		
18	1	3	3	1	3	3	*			*			*		
19	2	5	10	2	5	10	*			-*-			*		
20	2	4	8	1	4	4	1	5	5	*			RAIN		
21	--*--			-*-			RAIN			*			*		
22	--*--			1	3	3	*			*			*		
23	-*-			2	5	10	RAIN			*			*		
24	-*-			-*-			*			RAIN			*		
25	1	2	2	--*--			RAIN			*			RAIN		
26	1	4	4	--*--			RAIN			*			RAIN		
27	1	5	5	-*-			*			RAIN			*		
28	3	4	12	*			*			*			RAIN		
29	3	7	21!	-*-			-----			RAIN			RAIN		
30	1	6	6	-*-			-----			*			*		
31	1	4	4	-*-			-----			RAIN			-----		
TOTAL			126			103			5			6			19

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	17	26	18	22	35	5	3	126	48.6
JANUARY	3	0	3	10	4	22	23	38	103	39.8
FEBRUARY	0	0	0	0	0	5	0	0	5	1.9
MARCH	0	0	0	3	0	3	0	0	6	2.3
APRIL	0	0	0	0	0	7	12	0	19	7.3
TOTAL	3	17	29	31	26	72	40	41	259	
%	1.2	6.6	11.2	12.0	10.0	27.8	15.4	15.8		

WINTER: 1959/60

	DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL	
1	2	3	6	-*-			RAIN			*			*	
2	1	4	4	-*-			RAIN			RAIN			RAIN	
3	--*--			1	3	3	RAIN			2	3	6	RAIN	
4	1	3	3	*			*			*			RAIN	
5	1	3	3	1	5	5	*			*			RAIN	
6	7	4	28!	--*--			*			--*--			*	
7	2	8	16!	--*--			-*-			-*-			*	
8	2	6	12	-*-			-*-			1	5	5	RAIN	
9	1	6	6	-*-			1	3	3	1	4	4	RAIN	
10	1	3	3	1	3	3	1	3	3	--*--			RAIN	
11	1	4	4	2	4	8	1	3	3	-*-			RAIN	
12	1	3	3	4	2	8	1	3	3	-*-			*	
13	RAIN			1	3	3	2	3	6	1	3	3	RAIN	
14	-*-			1	3	3	2	5	10	RAIN			RAIN	
15	-*-			1	3	3	2	7	14	--*--			RAIN	
16	2	3	6	1	4	4	2	5	10	-*-			*	
17	3	6	18!	1	4	4	--*--			-*-			*	
18	2	7	14	3	3	9	--*--			-*-			*	
19	1	5	5	7	5	35!	1	4	4	-*-			*	
20	3	5	15!	1	4	4	--*--			-*-			*	
21	--*--			2	6	12	--*--			*			*	
22	1	3	3	1	7	7	-*-			*			*	
23	1	4	4	*			-*-			*			RAIN	
24	--*--			-*-			2	3	6	*			RAIN	
25	1	3	3	-*-			1	5	5	*			*	
26	--*--			-*-			2	3	6	-*-			*	
27	-*-			-*-			*			-*-			*	
28	1	4	4	1	3	3	*			-*-			*	
29	4	4	16!	-*-			RAIN			*			RAIN	
30	RAIN			2	3	6	-----			*			*	
31	RAIN			2	3	6	-----			*			-----	
TOTAL			176			126			73			18		0

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	0	31	98	9	15	19	4	176	44.8
JANUARY	21	44	9	22	0	0	11	19	126	32.1
FEBRUARY	9	0	4	11	6	13	24	6	73	18.6
MARCH	0	0	7	5	0	6	0	0	18	4.6
APRIL	0	0	0	0	0	0	0	0	0	0.0
TOTAL	30	44	51	136	15	34	54	29	393	
%	7.6	11.2	13.0	34.6	3.8	8.7	13.7	7.4		

WINTER: 1960/1

	DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
1	RAIN			-*-			-*-			RAIN			-*-		
2	RAIN			-*-			1	2	2	RAIN			-*-		
3	2	7	14	2	4	8	1	3	3	*			-*-		
4	2	6	12	--*--			1	3	3	*			1	2	2
5	--*--			2	4	8	2	3	6	*			2	3	6
6	-*-			--*--			1	4	4	*			-*-		
7	--*--			1	4	4	--*--			*			*		
8	1	3	3	1	4	4	RAIN			*			*		
9	1	2	2	--*--			RAIN			*			--*--		
10	-*-			-*-			1	6	6	*			*		
11	-*-			2	3	6	1	4	4	RAIN			*		
12	--*--			RAIN			RAIN			RAIN			RAIN		
13	-*-			-*-			*			*			RAIN		
14	-*-			-*-			*			*			*		
15	*			-*-			*			*			*		
16	*			-*-			*			*			*		
17	RAIN			-*-			*			RAIN			*		
18	-*-			2	5	10	*			1	5	5	*		
19	-*-			--*--			*			1	4	4	RAIN		
20	-*-			1	2	2	*			*			RAIN		
21	-*-			--*--			*			--*--			RAIN		
22	*			-*-			*			*			RAIN		
23	RAIN			-*-			-*-			*			RAIN		
24	1	3	3	1	4	4	-*-			*			RAIN		
25	RAIN			--*--			RAIN			*			*		
26	1	7	7	4	6	24!	RAIN			1	6	6	*		
27	1	7	7	3	8	24!	2	6	12	--*--			RAIN		
28	1	4	4	--*--			1	5	5	*			*		
29	1	3	3	3	6	18!	-----			RAIN			*		
30	--*--			1	5	5	-----			-*-			*		
31	1	3	3	--*--			-----			*			-----		
TOTAL			58			117			45			15			8

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	0	5	3	10	37	3	0	58	23.9
JANUARY	0	0	18	66	0	13	8	12	117	48.1
FEBRUARY	5	0	0	6	14	12	5	3	45	18.5
MARCH	0	0	0	0	0	6	5	4	15	6.2
APRIL	0	0	6	2	0	0	0	0	8	3.3
TOTAL	5	0	29	77	24	68	21	19	243	
%	2.1	0.0	11.9	31.7	9.9	28.0	8.6	7.8		

WINTER: 1961/2

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	1 3	3	1 4	4	1 5	5	4 3	12	1 7	7
2	3 5	15!	-*-		--*--		3 4	12	1 5	5
3	--*--		-*-		2 5	10	3 2	6	1 3	3
4	6 3	18!	--*--		1 5	5	1 3	3	1 3	3
5	1 5	5	1 5	5	*		-*-		1 3	3
6	--*--		RAIN		RAIN		-*-		1 3	3
7	--*--		1 6	6	2 4	8	-*-		1 3	3
8	-*-		4 5	20!	*		--*--		1 3	3
9	1 3	3	1 6	6	*		-*-		1 4	4
10	RAIN		3 6	18!	1 5	5	1 2	2	*	
11	RAIN		1 5	5	RAIN		-*-		--*--	
12	RAIN		4 7	28!	2 9	18!	1 3	3	RAIN	
13	RAIN		--*--		2 5	10	--*--		-*-	
14	*		1 3	3	--*--		--*--		*	
15	*		8 6	48!	RAIN		-*-		*	
16	*		1 6	6	2 10	20!	-*-		*	
17	-*-		3 7	21!	2 5	10	-*-		*	
18	-*-		1 4	4	--*--		1 2	2	RAIN	
19	-*-		2 5	10	*		1 2	2	RAIN	
20	-*-		1 4	4	*		-*-		RAIN	
21	-*-		1 5	5	*		1 2	2	*	
22	-*-		1 8	8	*		1 3	3	*	
23	-*-		--*--		-*-		-*-		*	
24	-*-		1 3	3	1 2	2	-*-		*	
25	1 3	3	RAIN		1 4	4	1 5	5	*	
26	-*-		-*-		1 4	4	1 4	4	*	
27	2 4	8	-*-		--*--		--*--		*	
28	4 4	16!	-*-		-*-		1 4	4	*	
29	--*--		-*-		-----		3 3	9	*	
30	--*--		RAIN		-----		1 3	3	*	
31	2 4	8	RAIN		-----		1 4	4	-----	
TOTAL		79		204		101		76		34

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	23	19	0	3	8	0	26	0	79	16.0
JANUARY	0	0	0	56	68	41	35	4	204	41.3
FEBRUARY	0	8	2	0	8	15	48	20	101	20.4
MARCH	12	6	0	9	7	0	7	35	76	15.4
APRIL	3	3	0	8	0	10	10	0	34	6.9
TOTAL	38	36	2	76	91	66	126	59	494	
%	7.7	7.3	0.4	15.4	18.4	13.4	25.5	11.9		

WINTER: 1962/3

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	-*-		1 7	7	-*-		*		*	
2	*		1 4	4	1 3	3	*		*	
3	*		1 4	4	1 3	3	*		2 2	4
4	*		2 5	10	-*-		*		2 4	8
5	*		2 4	8	2 4	8	*		1 4	4
6	*		1 3	3	2 8	16!	RAIN		-*-	
7	RAIN		-*-		1 6	6	RAIN		-*-	
8	2 5	10	-*-		1 4	4	RAIN		*	
9	1 6	6	-*-		-*-		RAIN		*	
10	RAIN		1 3	3	-*-		1 5	5	RAIN	
11	2 5	10	-*-		-*-		RAIN		-*-	
12	3 4	12	-*-		-*-		1 2	2	1 5	5
13	1 5	5	-*-		-*-		1 3	3	1 8	8
14	2 5	10	-*-		1 7	7	RAIN		*	
15	RAIN		-*-		1 5	5	RAIN		*	
16	1 5	5	-*-		-*-		RAIN		*	
17	2 4	8	-*-		-*-		RAIN		RAIN	
18	-*-		-*-		-*-		RAIN		RAIN	
19	2 3	6	1 2	2	-*-		RAIN		*	
20	1 5	5	1 5	5	1 2	2	RAIN		RAIN	
21	-*-		-*-		-*-		*		RAIN	
22	-*-		-*-		-*-		-*-		*	
23	2 4	8	-*-		-*-		*		*	
24	2 5	10	-*-		-*-		RAIN		*	
25	1 3	3	-*-		-*-		1 5	5	RAIN	
26	2 3	6	-*-		-*-		RAIN		*	
27	2 3	6	-*-		-*-		*		*	
28	-*-		-*-		-*-		1 4	4	*	
29	1 2	2	1 3	3	-----		1 4	4	RAIN	
30	1 5	5	3 4	12	-----		-*-		RAIN	
31	1 7	7	3 3	9	-----		*		-----	
TOTAL		124		70		54		23		29

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	11	20	0	0	26	30	12	25	124	41.3
JANUARY	0	60	7	0	0	3	0	0	70	23.3
FEBRUARY	3	3	46	0	0	0	2	0	54	18.0
MARCH	0	0	8	4	4	0	5	2	23	7.7
APRIL	0	12	0	0	0	13	0	4	29	9.7
TOTAL	14	95	61	4	30	46	19	31	300	
%	4.7	31.7	20.3	1.3	10.0	15.3	6.3	10.3		

WINTER 1963/4

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	*		RAIN		RAIN		*		-*-	
2	*		RAIN		RAIN		RAIN		-*-	
3	-*-		RAIN		1 6	6	1 3	3	1 3	3
4	1 4	4	1 2	2	2 5	10	-*-		-*-	
5	-*-		-*-		--*--		1 2	2	*	
6	1 2	2	--*--		1 3	3	-*-		-*-	
7	-*-		-*-		--*--		-*-		*	
8	-*-		-*-		*		-*-		*	
9	-*-		-*-		*		1 3	3	RAIN	
10	-*-		-*-		--*--		-*-		*	
11	-*-		-*-		-*-		*		*	
12	-*-		-*-		-*-		--*--		*	
13	-*-		--*--		-*-		RAIN		RAIN	
14	1 3	3	1 4	4	-*-		3 7	21!	*	
15	-*-		--*--		-*-		1 6	6	*	
16	--*--		--*--		-*-		--*--		*	
17	1 4	4	-*-		1 3	3	--*--		*	
18	1 4	4	*		--*--		--*--		*	
19	1 4	4	*		-*-		1 7	7	RAIN	
20	--*--		*		-*-		--*--		RAIN	
21	--*--		-*-		-*-		*		RAIN	
22	-*-		-*-		--*--		-*-		RAIN	
23	--*--		1 4	4	1 6	6	*		2 2	4
24	1 7	7	--*--		RAIN		4 6	24!	*	
25	1 7	7	*		RAIN		1 4	4	*	
26	--*--		*		*		*		RAIN	
27	*		RAIN		*		--*--		RAIN	
28	RAIN		*		*		-*-		*	
29	RAIN		RAIN		*		1 3	3	*	
30	RAIN		-*-		-----		-*-		RAIN	
31	*		RAIN		-----		-*-		-----	
TOTAL		35		10		28		73		7

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	2	8	0	0	14	0	4	7	35	22.9
JANUARY	0	4	0	0	0	6	0	0	10	6.5
FEBRUARY	0	3	0	6	0	16	3	0	28	18.3
MARCH	0	2	16	45	0	0	7	3	73	47.7
APRIL	4	3	0	0	0	0	0	0	7	4.6
TOTAL	6	20	16	51	14	22	14	10	153	
%	3.9	13.1	10.5	33.3	9.2	14.4	9.2	6.5		

WINTER 1964/5

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	-*-		1 3	3	-*-		--*--		*	
2	1 4	4	1 4	4	--*--		--*--		*	
3	1 5	5	1 3	3	-*-		1 7	7	*	
4	1 4	4	--*--		--*--		1 3	3	*	
5	RAIN		*		1 4	4	--*--		RAIN	
6	RAIN		*		RAIN		-*-		*	
7	RAIN		RAIN		*		1 5	5	*	
8	RAIN		2 4	8	1 2	2	1 2	2	*	
9	1 5	5	2 4	8	RAIN		-*-		RAIN	
10	--*--		2 4	8	*		--*--		RAIN	
11	RAIN		1 5	5	RAIN		-*-		RAIN	
12	RAIN		1 5	5	RAIN		*		RAIN	
13	--*--		3 4	12	1 7	7	RAIN		*	
14	-*-		3 6	18!	1 5	5	RAIN		*	
15	-*-		2 4	8	--*--		RAIN		*	
16	2 4	8	2 4	8	*		RAIN		RAIN	
17	1 4	4	1 4	4	RAIN		RAIN		RAIN	
18	-*-		--*--		1 2	2	1 3	3	2 5	10
19	1 2	2	--*--		1 3	3	1 2	2	2 5	10
20	1 3	3	-*-		--*--		-*-		--*--	
21	-*-		--*--		1 2	2	--*--		*	
22	-*-		-*-		1 2	2	1 4	4	RAIN	
23	-*-		2 4	8	1 2	2	--*--		*	
24	2 3	6	-*-		1 3	3	1 2	2	*	
25	-*-		1 2	2	1 3	3	1 3	3	RAIN	
26	--*--		--*--		1 4	4	2 3	6	RAIN	
27	1 3	3	--*--		1 3	3	*		2 3	6
28	2 5	10	-*-		2 4	8	*		2 3	6
29	2 5	10	-*-		-----		*		--*--	
30	3 5	15!	-*-		-----		*		*	
31	1 5	5	-*-		-----		*		-----	
TOTAL		84		104		50		37		32

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	4	0	0	8	3	51	4	14	84	27.4
JANUARY	0	0	0	8	18	48	30	0	104	33.9
FEBRUARY	6	6	0	0	0	0	24	14	50	16.3
MARCH	0	5	13	0	7	5	4	3	37	12.1
APRIL	6	6	0	0	0	0	10	10	32	20.4
TOTAL	16	17	13	16	28	104	72	41	307	
%	5.2	5.5	4.2	5.2	9.1	33.9	23.5	13.4		

WINTER 1965/6

	DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
1	1	5	5	2	3	6	*			*			-*-		
2	1	5	5	1	3	3	RAIN			*			-*-		
3	1	4	4	-*-			*			*			-*-		
4	1	5	5	*			RAIN			*			-*-		
5	1	3	3	RAIN			RAIN			*			-*-		
6	--*--			*			RAIN			*			1	4	4
7	1	4	4	*			-*-			*			RAIN		
8	1	4	4	*			1	5	5	RAIN			*		
9	5	4	20!	-*-			1	4	4	RAIN			3	5	15!
10	1	6	6	--*--			1	3	3	RAIN			1	4	4
11	--*--			--*--			1	3	3	2	5	10	--*--		
12	-*-			-*-			1	3	3	--*--			--*--		
13	-*-			-*-			1	3	3	-*-			-*-		
14	1	3	3	-*-			-*-			RAIN			-*-		
15	*			-*-			--*--			*			--*--		
16	-*-			-*-			-*-			*			-*-		
17	RAIN			-*-			-*-			*			1	3	3
18	1	4	4	-*-			-*-			*			--*--		
19	--*--			-*-			1	5	5	*			-*-		
20	1	3	3	-*-			1	4	4	RAIN			RAIN		
21	--*--			-*-			*			-*-			RAIN		
22	1	3	3	-*-			1	3	3	RAIN			RAIN		
23	1	3	3	1	2	2	--*--			2	6	12	RAIN		
24	1	3	3	-*-			1	3	3	1	7	7	*		
25	1	3	3	1	3	3	RAIN			1	5	5	*		
26	--*--			1	5	5	RAIN			1	3	3	RAIN		
27	--*--			1	3	3	RAIN			2	7	14	*		
28	-*-			RAIN			1	7	7	2	6	12	*		
29	1	5	5	RAIN			-----			1	5	5	*		
30	--*--			-*-			-----			RAIN			*		
31	1	3	3	-*-			-----			-*-			-----		
TOTAL			86			22			43			68			26

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	10	3	6	10	15	30	5	7	86	35.1
JANUARY	0	5	11	6	0	0	0	0	22	9.0
FEBRUARY	0	7	29	0	0	7	0	0	43	17.6
MARCH	0	0	0	0	3	0	48	17	68	27.8
APRIL	0	3	23	0	0	0	0	0	26	10.6
TOTAL	10	18	69	16	18	37	53	24	245	
%	4.1	7.3	28.2	6.5	7.3	15.1	21.6	9.6		

WINTER 1966/7

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	4 6	24!	--*--		RAIN		1 7	7	1 3	3
2	3 5	15!	--*--		RAIN		3 6	18!	--*--	
3	1 4	4	-*-		RAIN		RAIN		--*--	
4	1 3	3	-*-		*		*		RAIN	
5	--*--		-*-		RAIN		RAIN		3 7	21!
6	--*--		2 2	4	RAIN		RAIN		2 6	12
7	RAIN		--*--		*		RAIN		2 4	8
8	2 4	8	2 3	6	*		RAIN		*	
9	1 5	5	1 3	3	*		2 3	6	*	
10	2 4	8	-*-		*		4 5	20!	*	
11	--*--		RAIN		*		1 6	6	*	
12	2 5	10	*		-*-		--*--		*	
13	--*--		*		*		RAIN		*	
14	1 2	2	*		-*-		RAIN		*	
15	2 5	10	*		1 6	6	1 6	6	*	
16	RAIN		*		2 6	12	1 4	4	*	
17	RAIN		1 5	5	1 4	4	1 6	6	*	
18	1 7	7	2 4	8	1 3	3	--*--		*	
19	2 3	6	1 4	4	2 5	10	RAIN		*	
20	2 4	8	1 3	3	2 6	12	RAIN		RAIN	
21	1 4	4	3 5	15!	1 6	6	*		1 4	4
22	RAIN		1 4	4	--*--		RAIN		-*-	
23	1 5	5	2 5	10	1 4	4	-*-		*	
24	--*--		--*--		1 5	5	*		RAIN	
25	1 5	5	2 4	8	2 4	8	RAIN		*	
26	1 6	6	1 3	3	RAIN		2 4	8	RAIN	
27	1 5	5	RAIN		6 7	42!	1 6	6	*	
28	1 4	4	RAIN		3 6	18!	2 5	10	*	
29	--*--		RAIN		-----		1 5	5	*	
30	1 3	3	RAIN		-----		1 3	3	RAIN	
31	1 4	4	RAIN		-----		--*--		-----	
TOTAL		146		73		130		105		48

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	0	2	55	4	35	35	15	146	29.1
JANUARY	0	0	11	32	5	15	4	6	73	14.5
FEBRUARY	0	0	0	35	3	88	4	0	130	25.9
MARCH	0	6	0	0	14	43	34	8	105	20.9
APRIL	8	0	0	0	3	0	0	37	48	9.6
TOTAL	8	6	13	122	29	181	77	66	502	
%	1.6	1.2	2.6	24.3	5.8	36.1	15.3	13.1		

WINTER 1967/8

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	*		1 3	3	--*--		-*-		1 3	3
2	RAIN		1 3	3	--*--		-*-		3 4	12
3	*		1 3	3	1 3	3	-*-		3 5	15!
4	RAIN		--*--		2 6	12	RAIN		1 4	4
5	1 4	4	--*--		1 3	3	RAIN		1 4	4
6	--*--		2 3	6	2 5	10	*		1 3	3
7	--*--		1 4	4	1 4	4	*		--*--	
8	-*-		--*--		2 4	8	*		--*--	
9	1 4	4	--*--		1 4	4	RAIN		*	
10	2 3	6	1 4	4	--*--		*		*	
11	RAIN		--*--		--*--		RAIN		*	
12	RAIN		--*--		1 2	2	*		*	
13	*		1 3	3	--*--		*		*	
14	*		4 3	12	1 2	2	-*-		*	
15	RAIN		1 7	7	1 2	2	-*-		*	
16	-*-		1 4	4	--*--		RAIN		RAIN	
17	-*-		-*-		--*--		3 7	21!	RAIN	
18	-*-		*		-*-		2 5	10	RAIN	
19	-*-		*		2 2	4	3 5	15!	RAIN	
20	RAIN		*		--*--		--*--		*	
21	RAIN		-*-		2 2	4	3 3	9	RAIN	
22	RAIN		-*-		--*--		1 3	3	*	
23	*		1 4	4	--*--		--*--		*	
24	1 3	3	--*--		-*-		*		*	
25	1 3	3	*		-*-		RAIN		*	
26	*		RAIN		-*-		RAIN		*	
27	RAIN		RAIN		-*-		*		*	
28	2 5	10	--*--		-*-		RAIN		*	
29	2 4	8	*		-*-		RAIN		*	
30	1 4	4	*		-----		RAIN		*	
31	1 3	3	3 4	12	-----		RAIN		-----	
TOTAL		45		65		58		58		41

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	18	0	0	0	0	0	15	12	45	16.9
JANUARY	0	0	0	4	6	37	0	18	65	24.3
FEBRUARY	2	28	4	5	12	4	0	3	58	21.7
MARCH	0	0	0	0	0	45	13	0	58	21.7
APRIL	0	0	0	0	0	0	4	37	41	15.4
TOTAL	20	28	4	9	18	86	32	70	267	
%	7.5	10.5	1.5	3.4	6.7	32.2	12.0	26.2		

WINTER 1968/9

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	RAIN		*		2 3	6	1 3	3	1 4	4
2	*		*		2 6	12	-*-		*	
3	*		1 4	4	1 4	4	--*--		*	
4	*		1 4	4	--*--		*		*	
5	*		2 4	8	2 5	10	*		*	
6	-*-		1 2	2	2 4	8	-*-		*	
7	-*-		5 5	25!	--*--		-*-		*	
8	-*-		3 5	15!	--*--		--*--		*	
9	-*-		--*--		1 4	4	-*-		*	
10	-*-		3 5	15!	3 2	6	-*-		*	
11	-*-		--*--		1 4	4	-*-		RAIN	
12	-*-		2 3	6	--*--		-*-		1 4	4
13	-*-		2 5	10	1 3	3	1 5	5	--*--	
14	-*-		1 3	3	--*--		1 5	5	RAIN	
15	1 5	5	1 3	3	-*-		--*--		RAIN	
16	3 3	9	--*--		-*-		1 5	5	1 5	5
17	2 4	8	2 4	8	-*-		1 5	5	*	
18	2 4	8	1 4	4	-*-		1 5	5	*	
19	2 3	6	-*-		1 4	4	1 4	4	*	
20	--*--		RAIN		--*--		RAIN		-*-	
21	2 3	6	*		1 4	4	-*-		4 5	20!
22	1 6	6	*		2 4	8	*		1 6	6
23	--*--		RAIN		*		*		*	
24	--*--		*		1 5	5	1 3	3	RAIN	
25	2 3	6	RAIN		--*--		-*-		*	
26	1 3	3	*		-*-		-*-		*	
27	1 4	4	*		-*-		*		RAIN	
28	2 4	8	-*-		1 3	3	*		4 3	12
29	1 5	5	-*-		-----		RAIN		1 3	3
30	1 3	3	4 7	28!	-----		1 4	4	RAIN	
31	-*-		--*--		-----		--*--		-----	
TOTAL		76		135		81		39		54

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	8	14	0	19	0	6	0	29	76	19.7
JANUARY	0	0	56	22	8	39	10	0	135	35.1
FEBRUARY	12	15	9	0	6	22	6	11	81	21.0
MARCH	0	9	23	0	0	4	0	3	39	10.1
APRIL	0	26	0	0	0	4	17	7	54	14.1
TOTAL	20	64	88	41	14	75	33	50	385	
%	5.2	16.6	22.9	10.6	3.6	19.5	8.6	13.0		

WINTER 1969/70

	DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
1	--*--			1	3	3	3	7	21!	1	5	5	1	5	5
2	1	4	4	1	3	3	1	8	8	1	5	5	1	3	3
3	1	3	3	1	4	4	1	6	6	--*--			2	3	6
4	--*--			--*--			1	3	3	1	3	3	1	3	3
5	1	3	3	1	3	3	3	2	6	2	3	6	3	5	15!
6	1	4	4	--*--			1	3	3	--*--			2	4	8
7	*			--*--			--*--			3	6	18!	2	3	6
8	*			--*--			--*--			1	4	4	3	4	12
9	*			1	5	5	-*-			1	3	3	1	3	3
10	RAIN			--*--			-*-			-*-			-*-		
11	-*-			1	3	3	-*-			2	4	8	-*-		
12	-*-			1	3	3	-*-			2	5	10	-*-		
13	2	7	14	1	2	2	3	3	9	-*-			-*-		
14	1	7	7	3	5	15!	--*--			-*-			RAIN		
15	1	3	3	1	6	6	2	3	6	-*-			*		
16	--*--			--*--			1	3	3	RAIN			*		
17	1	4	4	2	5	10	2	4	8	RAIN			*		
18	1	4	4	RAIN			--*--			-*-			RAIN		
19	1	6	6	RAIN			5	4	20!	1	4	4	*		
20	1	3	3	*			1	3	3	-*-			1	3	3
21	RAIN			RAIN			2	3	6	*			RAIN		
22	-*-			*			1	4	4	*			RAIN		
23	*			1	4	4	--*--			*			RAIN		
24	RAIN			1	4	4	-*-			*			*		
25	-*-			--*--			-*-			*			RAIN		
26	-*-			-*-			1	2	2	1	4	4	1	3	3
27	-*-			-*-			1	2	2	1	4	4	--*--		
28	-*-			-*-			1	3	3	--*--			1	3	3
29	-*-			1	4	4	-----			RAIN			*		
30	-*-			--*--			-----			3	3	9	*		
31	-*-			--*--			-----			3	5	15!	-----		
TOTAL			55			69			113			98			70

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	0	4	34	0	3	7	7	55	13.6
JANUARY	0	0	36	20	0	0	0	13	69	17.0
FEBRUARY	2	0	0	35	20	18	12	26	113	27.9
MARCH	15	0	10	0	8	9	31	25	98	24.2
APRIL	34	0	0	0	0	18	12	6	70	17.3
TOTAL	51	0	50	89	28	48	62	77	405	
%	12.6	0.0	12.3	22.0	6.9	11.9	15.3	19.0		

WINTER 1970/1

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	-*-		-*-		-*-		1 4	4	-*-	
2	2 2	4	-*-		*		--*--		1 3	3
3	--*--		-*-		*		--*--		1 2	2
4	2 4	8	-*-		*		1 3	3	--*--	
5	RAIN		-*-		-*-		-*-		-*-	
6	1 6	6	RAIN		-*-		1 2	2	*	
7	--*--		RAIN		*		*		*	
8	*		RAIN		--*--		*		*	
9	*		RAIN		-*-		1 4	4	*	
10	-*-		*		-*-		1 2	2	*	
11	-*-		*		1 3	3	RAIN		*	
12	RAIN		-*-		RAIN		*		*	
13	-*-		-*-		1 5	5	*		*	
14	-*-		-*-		1 5	5	-*-		*	
15	*		-*-		--*--		-*-		*	
16	RAIN		-*-		-*-		*		1 4	4
17	*		RAIN		-*-		*		*	
18	*		1 4	4	-*-		2 3	6	*	
19	RAIN		--*--		1 3	3	1 6	6	*	
20	-*-		2 3	6	--*--		1 5	5	*	
21	-*-		3 5	15!	--*--		--*--		*	
22	1 3	3	1 3	3	-*-		-*-		RAIN	
23	2 4	8	1 4	4	*		*		RAIN	
24	1 3	3	2 3	6	*		RAIN		*	
25	1 2	2	--*--		-*-		-*-		1 2	2
26	1 3	3	-*-		-*-		*		RAIN	
27	1 3	3	2 3	6	1 3	3	RAIN		*	
28	-*-		1 3	3	--*--		RAIN		RAIN	
29	2 4	8	1 3	3	-----		RAIN		RAIN	
30	1 4	4	1 2	2	-----		RAIN		*	
31	-*-		--*--		-----		*		-----	
TOTAL		52		52		19		32		11

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	7	16	0	0	0	18	0	11	52	31.3
JANUARY	0	14	15	7	16	0	0	0	52	31.3
FEBRUARY	0	0	0	3	6	5	5	0	19	11.4
MARCH	2	17	0	3	4	0	6	0	32	19.3
APRIL	0	4	3	0	0	4	0	0	11	6.7
TOTAL	9	51	18	13	26	27	11	11	166	
%	5.4	30.7	10.7	7.8	15.7	16.3	6.6	6.6		

WINTER 1971/2

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	-*-		1 4	4	1 4	4	1 4	4	RAIN	
2	-*-		1 3	3	2 6	12	2 4	8	RAIN	
3	RAIN		--*--		2 6	12	5 7	35!	RAIN	
4	*		-*-		2 2	4	1 7	7	RAIN	
5	*		-*-		1 3	3	--*--		RAIN	
6	*		-*-		1 4	4	1 5	5	RAIN	
7	RAIN		1 3	3	-*-		1 4	4	RAIN	
8	RAIN		1 6	6	-*-		--*--		*	
9	*		1 4	4	-*-		--*--		RAIN	
10	RAIN		2 5	10	1 4	4	-*-		RAIN	
11	RAIN		RAIN		--*--		-*-		1 4	4
12	RAIN		3 7	21!	1 2	2	*		*	
13	*		3 3	9	1 4	4	-*-		*	
14	RAIN		1 4	4	--*--		*		*	
15	*		2 5	10	2 5	10	*		*	
16	*		6 6	36!	3 6	18!	RAIN		RAIN	
17	*		2 6	12	1 4	4	*		RAIN	
18	RAIN		2 6	12	-*-		*		*	
19	2 6	12	--*--		-*-		RAIN		*	
20	RAIN		--*--		-*-		*		*	
21	2 7	14	--*--		-*-		*		*	
22	1 6	6	1 4	4	-*-		*		*	
23	*		2 4	8	-*-		*		*	
24	*		--*--		-*-		*		*	
25	*		--*--		-*-		*		*	
26	2 3	6	1 3	3	-*-		1 4	4	*	
27	-*-		1 6	6	-*-		1 4	4	*	
28	1 3	3	1 2	2	--*--		--*--		RAIN	
29	--*--		-*-		-*-		1 4	4	RAIN	
30	-*-		1 2	2	-----		--*--		*	
31	-*-		1 2	2	-----		*		-----	
TOTAL		41		161		81		75		4

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	3	0	0	12	6	20	0	0	41	11.3
JANUARY	2	7	4	106	32	4	0	6	161	44.5
FEBRUARY	4	18	22	31	6	0	0	0	81	22.4
MARCH	0	0	4	59	4	4	4	0	75	20.7
APRIL	4	0	0	0	0	0	0	0	4	1.1
TOTAL	13	25	30	208	48	28	4	6	362	
%	4.0	6.9	8.3	57.5	13.3	7.7	1.1	1.7		

WINTER 1972/3

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	1 6	6	RAIN		*		--*--		--*--	
2	--*--		RAIN		*		--*--		1 4	4
3	-*-		-*-		*		*		RAIN	
4	2 4	8	-*-		*		-*-		RAIN	
5	3 7	21!	-*-		*		--*--		2 4	8
6	1 5	5	-*-		RAIN		-*-		2 7	14
7	1 2	2	-*-		1 7	7	*		1 5	5
8	-*-		-*-		--*--		*		1 4	4
9	1 4	4	-*-		1 3	3	*		-*-	
10	3 5	15!	-*-		1 6	6	*		RAIN	
11	4 7	28!	-*-		2 5	10	*		-*-	
12	RAIN		-*-		2 5	10	*		-*-	
13	1 8	8	-*-		1 4	4	*		*	
14	*		2 5	10	--*--		*		*	
15	*		3 5	15!	-*-		*		*	
16	*		--*--		-*-		*		*	
17	-*-		-*-		-*-		*		*	
18	*		-*-		*		*		RAIN	
19	-*-		--*--		RAIN		*		1 3	3
20	-*-		2 6	12	*		*		1 3	3
21	*		3 7	21!	1 5	5	*		1 3	3
22	-*-		--*--		2 5	10	*		*	
23	--*--		RAIN		1 5	5	*		--*--	
24	-*-		*		1 4	4	RAIN		*	
25	1 4	4	1 4	4	--*--		*		RAIN	
26	1 5	5	1 5	5	-*-		-*-		*	
27	1 4	4	--*--		--*--		RAIN		RAIN	
28	1 5	5	*		-*-		-*-		-*-	
29	--*--		RAIN		-----		RAIN		*	
30	*		-*-		-----		1 6	6	5 3	15!
31	*		-*-		-----		2 5	10	-----	
TOTAL		115		67		64		16		59

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	0	0	18	36	61	0	0	115	35.8
JANUARY	0	0	15	43	4	5	0	0	67	20.9
FEBRUARY	0	0	0	0	0	31	33	0	64	19.9
MARCH	0	0	0	0	6	10	0	0	16	5.0
APRIL	6	0	0	0	0	22	0	31	59	18.4
TOTAL	6	0	15	61	46	129	33	31	321	
%	1.9	0.0	4.7	19.0	14.3	40.2	10.3	9.7		

WINTER 1973/4

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	-*-		--*--		2 5	10	1 4	4	*	
2	*		-*-		1 4	4	-*-		*	
3	*		1 5	5	--*--		2 3	6	*	
4	*		RAIN		-*-		2 4	8	*	
5	RAIN		RAIN		--*--		-*-		*	
6	-*-		1 4	4	-*-		--*--		*	
7	2 4	8	1 6	6	--*--		*		*	
8	--*--		4 4	16!	2 4	8	--*--		*	
9	1 5	5	--*--		1 3	3	1 4	4	*	
10	RAIN		5 6	30!	2 5	10	1 3	3	RAIN	
11	1 5	5	8 6	48!	--*--		1 3	3	*	
12	2 6	12	3 8	24!	--*--		2 3	6	*	
13	2 6	12	1 5	5	-*-		1 3	3	*	
14	1 4	4	1 6	6	2 3	6	1 2	2	*	
15	1 6	6	2 4	8	1 5	5	1 3	3	*	
16	2 6	12	2 4	8	1 4	4	1 3	3	*	
17	1 6	6	RAIN		*		2 6	12	*	
18	4 4	16!	*		-*-		1 4	4	*	
19	6 6	36!	*		*		2 3	6	*	
20	1 5	5	*		RAIN		-*-		*	
21	1 3	3	--*--		*		1 3	3	*	
22	1 3	3	1 3	3	-*-		*		*	
23	--*--		2 6	12	-*-		*		*	
24	-*-		--*--		*		*		*	
25	--*--		1 5	5	*		-*-		*	
26	*		3 5	15!	*		*		*	
27	*		4 3	12	-*-		RAIN		*	
28	*		2 7	14	--*--		*		RAIN	
29	RAIN		3 7	21!	-----		*		*	
30	--*--		3 7	21!	-----		*		RAIN	
31	-*-		--*--		-----		*		-----	
TOTAL		133		263		50		70		0

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	52	3	0	28	28	18	4	133	25.8
JANUARY	0	0	0	95	148	20	0	0	263	51.0
FEBRUARY	0	0	0	31	16	3	0	0	50	9.7
MARCH	14	5	19	4	13	12	3	0	70	13.6
APRIL	0	0	0	0	0	0	0	0	0	0.0
TOTAL	14	57	22	130	205	63	21	4	516	
%	2.7	11.0	4.3	25.2	39.7	12.2	4.1	0.8		

WINTER 1974/5

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	RAIN		*		*		*		RAIN	
2	*		*		*		-*-		1 4	4
3	RAIN		-*-		*		RAIN		2 6	12
4	2 5	10	*		*		*		-*-	
5	*		RAIN		-*-		RAIN		-*-	
6	*		1 6	6	-*-		RAIN		1 3	3
7	*		-*-		-*-		-*-		3 6	18!
8	RAIN		RAIN		-*-		-*-		2 10	20!
9	2 5	10	RAIN		*		-*-		--*--	
10	1 4	4	RAIN		-*-		1 4	4	-*-	
11	1 3	3	RAIN		1 2	2	--*--		1 3	3
12	1 4	4	RAIN		1 2	2	-*-		1 4	4
13	1 6	6	RAIN		2 3	6	-*-		RAIN	
14	--*--		2 6	12	1 3	3	-*-		RAIN	
15	2 3	6	3 6	18!	1 2	2	-*-		*	
16	3 5	15!	--*--		2 6	12	-*-		RAIN	
17	3 6	18!	-*-		1 5	5	-*-		RAIN	
18	--*--		-*-		--*--		-*-		*	
19	RAIN		2 3	6	--*--		-*-		RAIN	
20	RAIN		--*--		--*--		*		*	
21	RAIN		1 5	5	--*--		1 4	4	RAIN	
22	RAIN		6 5	30!	--*--		--*--		*	
23	RAIN		2 7	14	*		--*--		*	
24	--*--		2 5	10	*		1 4	4	*	
25	RAIN		1 7	7	-*-		1 4	4	*	
26	1 3	3	1 4	4	-*-		1 5	5	*	
27	RAIN		--*--		*		1 4	4	*	
28	RAIN		2 4	8	*		1 4	4	RAIN	
29	-*-		2 5	10	-----		1 4	4	RAIN	
30	*		1 6	6	-----		1 3	3	RAIN	
31	*		RAIN		-----		-*-		-----	
TOTAL		79		136		32		36		64

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	0	0	0	15	25	35	4	79	22.8
JANUARY	0	6	0	8	60	24	33	5	136	39.2
FEBRUARY	0	6	7	14	5	0	0	0	32	9.2
MARCH	4	4	0	4	0	0	4	20	36	10.4
APRIL	16	0	0	0	3	7	18	20	64	18.4
TOTAL	20	16	7	26	83	56	90	49	347	
%	5.8	4.6	2.0	7.5	23.9	16.1	25.9	14.1		

WINTER 1975/6

	DECEMBER		JANUARY			FEBRUARY			MARCH			APRIL		
1	RAIN		1	4	4	-*-			*			2	2	4
2	RAIN		4	6	24!	1	3	3	*			--*--		
3	*		1	6	6	--*--			*			1	3	3
4	*		--*--			--*--			*			*		
5	*		2	4	8	-*-			*			*		
6	*		RAIN			1	3	3	-*-			*		
7	*		RAIN			1	3	3	-*-			1	2	2
8	-*-		-*-			1	3	3	-*-			*		
9	*		RAIN			--*--			1	3	3	*		
10	*		RAIN			1	4	4	--*--			*		
11	RAIN		*			1	4	4	1	4	4	*		
12	RAIN		RAIN			1	4	4	1	3	3	*		
13	-*-		1	3	3	1	3	3	1	2	2	1	5	5
14	-*-		--*--			1	4	4	1	3	3	1	3	3
15	*		*			--*--			1	4	4	-*-		
16	*		*			--*--			1	3	3	*		
17	*		*			-*-			--*--			*		
18	*		2	6	12	-*-			*			*		
19	*		3	7	21!	-*-			--*--			*		
20	*		2	6	12	-*-			1	5	5	*		
21	RAIN		2	5	10	1	4	4	2	4	8	*		
22	RAIN		2	4	8	RAIN			--*--			*		
23	-*-		1	4	4	*			--*--			*		
24	RAIN		1	4	4	*			2	4	8	*		
25	*		--*--			*			1	3	3	*		
26	*		1	3	3	*			2	4	8	1	2	2
27	*		--*--			*			--*--			*		
28	RAIN		2	6	12	*			RAIN			*		
29	*		1	5	5	*			1	5	5	*		
30	RAIN		--*--			-----			1	3	3	RAIN		
31	RAIN		--*--			-----			2	4	8	-----		
TOTAL		0			136			35			70			19

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	0	0	0	0	0	0	0	0	0.0
JANUARY	4	0	17	0	24	32	40	19	136	52.3
FEBRUARY	3	0	6	10	4	4	8	0	35	13.5
MARCH	0	0	12	20	11	24	3	0	70	26.9
APRIL	0	0	0	5	0	7	0	7	19	7.3
TOTAL	7	0	35	35	39	67	51	26	260	
%	2.7	0.0	13.5	13.5	15.0	25.8	19.6	10.0		

WINTER 1976/7

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	-*-		--*--		1 3	3	*		RAIN	
2	-*-		--*--		2 4	8	RAIN		3 6	18!
3	1 3	3	1 3	3	--*--		RAIN		--*--	
4	-*-		RAIN		1 4	4	-*-		*	
5	1 3	3	*		--*--		*		RAIN	
6	1 5	5	-*-		2 2	4	*		2 6	12
7	-*-		-*-		1 4	4	*		1 5	5
8	-*-		-*-		-*-		*		1 3	3
9	--*--		2 5	10	1 4	4	RAIN		1 2	2
10	--*--		2 4	8	1 7	7	2 5	10	RAIN	
11	1 3	3	--*--		1 6	6	RAIN		*	
12	1 2	2	1 3	3	--*--		-*-		RAIN	
13	-*-		2 3	6	1 3	3	RAIN		1 5	5
14	-*-		2 5	10	1 3	3	2 4	8	--*--	
15	1 2	2	2 6	12	--*--		RAIN		*	
16	-*-		--*--		--*--		RAIN		RAIN	
17	1 4	4	-*-		1 5	5	2 5	10	-*-	
18	--*--		1 3	3	1 6	6	RAIN		-*-	
19	1 3	3	2 4	8	1 4	4	RAIN		*	
20	2 4	8	2 4	8	-*-		1 3	3	*	
21	1 4	4	1 6	6	1 3	3	--*--		RAIN	
22	--*--		--*--		1 4	4	1 2	2	RAIN	
23	--*--		-*-		1 3	3	1 3	3	RAIN	
24	-*-		-*-		--*--		1 2	2	RAIN	
25	--*--		--*--		--*--		*		RAIN	
26	1 3	3	--*--		-*-		1 3	3	RAIN	
27	1 4	4	-*-		-*-		1 4	4	RAIN	
28	1 3	3	-*-		-*-		--*--		RAIN	
29	2 3	6	1 2	2	-----		--*--		RAIN	
30	1 5	5	1 6	6	-----		3 5	15!	*	
31	--*--		--*--		-----		RAIN		-----	
TOTAL		58		85		71		60		45

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	3	4	15	5	15	5	11	0	58	18.2
JANUARY	11	28	0	25	6	5	10	0	85	26.6
FEBRUARY	0	23	13	12	15	4	0	4	71	22.3
MARCH	10	2	5	18	25	0	0	0	60	18.8
APRIL	0	0	0	0	0	0	35	10	45	14.1
TOTAL	24	57	33	60	61	14	56	14	319	
%	7.5	17.9	10.3	18.8	19.1	4.4	17.6	4.4		

WINTER 1977/8

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	-*-		RAIN		2 4	8	2 5	10	2 4	8
2	--*--		2 4	8	--*--		1 5	5	--*--	
3	--*--		-*-		1 3	3	*		-*-	
4	-*-		-*-		--*--		-*-		*	
5	-*-		*		1 3	3	-*-		*	
6	1 5	5	*		2 3	6	--*--		*	
7	1 4	4	*		1 2	2	RAIN		*	
8	2 3	6	1 5	5	-*-		*		*	
9	1 3	3	2 4	8	-*-		RAIN		1 3	3
10	RAIN		1 4	4	-*-		*		--*--	
11	RAIN		1 5	5	1 3	3	RAIN		--*--	
12	*		1 4	4	1 4	4	*		1 2	2
13	*		*		1 3	3	1 3	3	1 3	3
14	*		*		-*-		RAIN		--*--	
15	*		-*-		1 2	2	2 4	8	-*-	
16	*		-*-		-*-		1 5	5	*	
17	1 3	3	-*-		-*-		--*--		*	
18	-*-		-*-		-*-		-*-		*	
19	*		--*--		--*--		2 4	8	*	
20	*		-*-		--*--		--*--		*	
21	-*-		2 5	10	-*-		--*--		*	
22	RAIN		1 6	6	1 3	3	2 3	6	*	
23	RAIN		1 5	5	--*--		1 2	2	*	
24	*		2 4	8	1 4	4	1 3	3	RAIN	
25	*		--*--		1 4	4	--*--		1 3	3
26	1 3	3	-*-		--*--		1 4	4	1 2	2
27	--*--		2 3	6	-*-		RAIN		2 3	6
28	1 6	6	7 7	49!	*		RAIN		1 4	4
29	1 4	4	5 7	35!	-----		2 5	10	1 3	3
30	1 6	6	1 3	3	-----		RAIN		--*--	
31	*		1 3	3	-----		RAIN		-----	
TOTAL		40		159		45		64		34

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	3	15	0	0	6	4	12	40	11.7
JANUARY	44	49	0	24	13	12	8	9	159	46.5
FEBRUARY	4	0	14	7	15	0	0	5	45	13.2
MARCH	5	0	0	15	10	26	8	0	64	18.7
APRIL	3	15	8	0	0	0	3	5	34	9.9
TOTAL	56	67	37	46	38	44	23	31	342	
%	16.4	19.6	10.8	13.5	11.1	12.9	6.7	9.1		

WINTER 1978/9

	DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
1	-*-			3	3	9	--*--			RAIN			-*-		
2	1	6	6	--*--			-*-			RAIN			1	2	2
3	2	4	8	--*--			-*-			2	5	10	1	2	2
4	1	7	7	1	3	3	-*-			4	7	28!	1	3	3
5	--*--			-*-			-*-			1	6	6	-*-		
6	--*--			1	6	6	-*-			1	5	5	1	2	2
7	7	7	49!	1	4	4	-*-			--*--			2	3	6
8	2	7	14	1	4	4	-*-			2	6	12	1	5	5
9	--*--			2	4	8	-*-			1	5	5	1	3	3
10	RAIN			1	4	4	-*-			1	3	3	3	3	9
11	RAIN			1	5	5	--*--			3	6	18!	*		
12	RAIN			--*--			--*--			1	7	7	RAIN		
13	*			-*-			--*--			1	3	3	*		
14	1	3	3	1	2	2	-*-			1	3	3	RAIN		
15	1	3	3	1	4	4	-*-			1	4	4	*		
16	-*-			1	3	3	1	5	5	--*--			*		
17	-*-			1	4	4	1	3	3	1	4	4	*		
18	-*-			--*--			1	4	4	--*--			*		
19	--*--			2	5	10	--*--			--*--			*		
20	1	2	2	1	6	6	--*--			3	5	15!	*		
21	1	4	4	--*--			1	4	4	1	5	5	*		
22	1	2	2	-*-			-*-			--*--			RAIN		
23	1	2	2	-*-			--*--			--*--			RAIN		
24	3	4	12	1	3	3	-*-			1	4	4	RAIN		
25	1	7	7	2	3	6	-*-			1	4	4	*		
26	1	3	3	1	3	3	2	6	12	-*-			*		
27	1	4	4	--*--			--*--			2	2	4	*		
28	1	5	5	1	6	6	-*-			3	5	15!	*		
29	1	7	7	1	5	5	-----			1	7	7	RAIN		
30	1	4	4	1	3	3	-----			--*--			-*-		
31	--*--			--*--			-----			-*-			-----		
TOTAL			142			98			28			162			32

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	22	97	21	2	0	0	0	142	30.7
JANUARY	4	7	18	15	32	11	6	5	98	21.2
FEBRUARY	0	5	3	8	12	0	0	0	28	6.1
MARCH	4	4	4	4	50	56	6	34	162	35.1
APRIL	0	25	0	0	0	2	0	5	32	6.9
TOTAL	8	63	122	48	96	69	12	44	462	
%	1.7	13.6	26.4	10.4	20.8	14.9	2.6	9.5		

WINTER 1979/80

	DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL	
1	RAIN			--*--			--*--			RAIN			*	
2	RAIN			--*--			-*-			-*-			RAIN	
3	RAIN			1	5	5	1	3	3	-*-			RAIN	
4	RAIN			1	6	6	--*--			-*-			*	
5	--*--			2	6	12	1	5	5	--*--			*	
6	--*--			2	5	10	--*--			1	3	3	RAIN	
7	4	7	28!	--*--			--*--			1	4	4	RAIN	
8	1	4	4	--*--			--*--			-*-			RAIN	
9	RAIN			--*--			4	3	12	1	2	2	RAIN	
10	RAIN			-*-			-*-			-*-			*	
11	-*-			-*-			RAIN			RAIN			*	
12	3	4	12	-*-			RAIN			*			*	
13	1	6	6	1	3	3	RAIN			*			*	
14	1	3	3	--*--			RAIN			*			RAIN	
15	1	2	2	--*--			*			-*-			*	
16	5	4	20!	-*-			-*-			--*--			RAIN	
17	4	7	28!	-*-			RAIN			3	5	15!	*	
18	--*--			-*-			RAIN			--*--			RAIN	
19	--*--			--*--			RAIN			--*--			-*-	
20	-*-			1	4	4	RAIN			1	3	3	*	
21	--*--			6	5	30!	RAIN			2	3	6	RAIN	
22	--*--			4	5	20!	*			--*--			RAIN	
23	-*-			1	3	3	*			2	3	6	RAIN	
24	-*-			1	3	3	-*-			5	5	25!	RAIN	
25	2	5	10	-*-			*			RAIN			*	
26	3	5	15!	--*--			*			RAIN			*	
27	1	3	3	1	3	3	*			-*-			RAIN	
28	--*--			1	3	3	*			-*-			*	
29	-*-			2	3	6	*			1	4	4	RAIN	
30	-*-			2	4	8	-----			RAIN			*	
31	-*-			--*--			-----			RAIN			-----	
TOTAL			131			116			20			68		0

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	28	4	56	13	28	2	0	131	39.1
JANUARY	0	37	36	12	9	12	10	0	116	34.6
FEBRUARY	0	3	17	0	0	0	0	0	20	6.0
MARCH	6	4	40	9	3	2	0	4	68	20.3
APRIL	0	0	0	0	0	0	0	0	0	0.0
TOTAL	6	72	97	77	25	42	12	4	335	
%	1.8	21.5	29.0	23.0	7.5	12.5	3.6	1.2		

WINTER 1980/1

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	--*--		2 6	12	RAIN		2 6	12	*	
2	1 4	4	RAIN		1 6	6	1 5	5	*	
3	1 3	3	1 6	6	1 4	4	--*--		*	
4	1 4	4	1 5	5	--*--		-*-		*	
5	1 4	4	2 2	4	*		1 2	2	*	
6	1 4	4	--*--		RAIN		1 5	5	*	
7	--*--		1 4	4	RAIN		RAIN		*	
8	*		RAIN		*		*		*	
9	*		1 4	4	*		*		*	
10	RAIN		--*--		*		RAIN		*	
11	*		2 3	6	1 3	3	*		RAIN	
12	RAIN		1 6	6	1 6	6	RAIN		*	
13	RAIN		1 5	5	--*--		RAIN		*	
14	2 5	10	1 6	6	--*--		-*-		*	
15	--*--		1 5	5	--*--		1 3	3	*	
16	*		1 4	4	-*-		1 3	3	*	
17	1 5	5	--*--		--*--		1 3	3	*	
18	1 4	4	2 3	6	--*--		1 7	7	*	
19	1 4	4	1 7	7	-*-		--*--		*	
20	1 3	3	1 3	3	-*-		1 3	3	*	
21	1 2	2	RAIN		--*--		1 4	4	*	
22	RAIN		*		--*--		--*--		-*-	
23	1 5	5	*		1 3	3	--*--		1 2	2
24	1 3	3	1 7	7	-*-		RAIN		--*--	
25	1 4	4	2 4	8	--*--		RAIN		--*--	
26	1 4	4	RAIN		--*--		RAIN		-*-	
27	*		*		1 5	5	RAIN		*	
28	*		*		2 6	12	RAIN		*	
29	RAIN		*		-----		*		*	
30	2 5	10	*		-----		*		*	
31	1 7	7	*		-----		*		-----	
TOTAL		80		98		39		47		2

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	4	0	0	9	5	47	4	11	80	30.1
JANUARY	0	0	4	6	0	24	24	40	98	36.8
FEBRUARY	0	3	17	0	9	10	0	0	39	14.7
MARCH	0	22	2	0	0	3	10	10	47	17.7
APRIL	0	0	0	2	0	0	0	0	2	0.8
TOTAL	4	25	23	17	14	84	38	61	266	
%	1.5	9.4	8.6	6.4	5.3	31.6	14.3	22.9		

WINTER 1981/2

	DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
1	-*-		-*-		-*-		2 6	12	-*-	
2	*		3 4	12	-*-		6 7	42!	*	
3	RAIN		4 6	24!	-*-		3 8	24!	*	
4	--*--		2 5	10	1 5	5	--*--		RAIN	
5	--*--		1 6	6	RAIN		1 4	4	*	
6	--*--		--*--		1 6	6	1 7	7	RAIN	
7	-*-		-*-		1 6	6	1 3	3	3 3	9
8	--*--		1 4	4	1 5	5	1 5	5	--*--	
9	-*-		--*--		1 5	5	2 6	12	1 4	4
10	-*-		--*--		1 4	4	1 4	4	--*--	
11	-*-		-*-		1 4	4	3 7	21!	--*--	
12	-*-		-*-		3 7	21!	1 6	6	-*-	
13	2 5	10	--*--		1 7	7	1 5	5	*	
14	3 7	21!	--*--		--*--		1 7	7	*	
15	-*-		-*-		--*--		--*--		*	
16	--*--		--*--		-*-		1 5	5	*	
17	1 3	3	--*--		1 2	2	2 6	12	*	
18	--*--		--*--		--*--		--*--		*	
19	1 6	6	1 4	4	--*--		-*-		*	
20	--*--		1 4	4	-*-		1 3	3	*	
21	1 5	5	1 5	5	--*--		--*--		*	
22	-*-		1 5	5	-*-		--*--		*	
23	-*-		--*--		-*-		*		*	
24	-*-		-*-		1 6	6	*		*	
25	-*-		2 4	8	2 2	4	*		*	
26	--*--		2 4	8	1 6	6	*		*	
27	--*--		1 5	5	--*--		*		*	
28	1 5	5	2 7	14	2 6	12	*		RAIN	
29	1 4	4	RAIN		-----		1 4	4	RAIN	
30	3 4	12	RAIN		-----		*		RAIN	
31	--*--		*		-----		*		-----	
TOTAL		66		109		93		176		13

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	3	16	20	21	6	0	0	0	66	14.4
JANUARY	0	52	0	8	9	30	5	5	109	23.9
FEBRUARY	0	2	5	27	32	23	4	0	93	20.4
MARCH	4	3	0	0	50	115	4	0	176	38.5
APRIL	0	0	0	0	0	13	0	0	13	2.8
TOTAL	7	73	25	56	97	181	13	5	457	
%	1.5	16.0	5.5	12.3	21.2	39.6	2.8	1.1		

WINTER 1982/3

	DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
1	*			1	4	4	1	5	5	1	5	5	--*--		
2	-*-			3	5	15!	1	6	6	--*--			1	4	4
3	-*-			1	6	6	--*--			--*--			1	3	3
4	1	4	4	1	6	6	1	5	5	*			1	4	4
5	--*--			RAIN			4	5	20!	*			1	2	2
6	-*-			5	7	35!	2	6	12	*			-*-		
7	4	7	28!	1	6	6	3	7	21!	*			-*-		
8	1	5	5	2	8	16!	--*--			*			*		
9	2	4	8	1	6	6	1	3	3	*			RAIN		
10	1	4	4	RAIN			3	3	9	RAIN			1	3	3
11	-*-			RAIN			1	5	5	--*--			--*--		
12	-*-			1	5	5	1	4	4	--*--			--*--		
13	-*-			2	5	10	-*-			RAIN			*		
14	1	4	4	1	4	4	-*-			RAIN			*		
15	3	5	15!	RAIN			-*-			RAIN			*		
16	--*--			*			-*-			*			RAIN		
17	1	6	6	RAIN			-*-			RAIN			-*-		
18	5	4	20!	1	9	9	-*-			RAIN			-*-		
19	4	5	20!	--*--			-*-			RAIN			1	3	3
20	1	7	7	--*--			-*-			2	2	4	1	3	3
21	1	7	7	*			-*-			2	6	12	--*--		
22	--*--			-*-			-*-			1	6	6	RAIN		
23	1	5	5	1	5	5	-*-			1	6	6	1	3	3
24	*			RAIN			--*--			2	5	10	1	4	4
25	*			2	7	14	-*-			1	5	5	*		
26	1	5	5	RAIN			-*-			1	4	4	*		
27	1	5	5	-*-			1	5	5	--*--			*		
28	--*--			RAIN			--*--			--*--			RAIN		
29	*			2	6	12	-----			1	4	4	RAIN		
30	RAIN			--*--			-----			1	5	5	RAIN		
31	*			4	5	20!	-----			1	4	4	-----		
TOTAL			143			173			95			65			29

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	0	0	28	36	38	41	0	143	28.3
JANUARY	0	0	0	20	34	96	9	14	173	34.3
FEBRUARY	33	6	0	0	10	20	5	21	95	18.8
MARCH	0	0	0	0	23	14	13	15	65	12.9
APRIL	6	7	2	0	0	0	0	14	29	5.7
TOTAL	39	13	2	48	103	168	68	64	505	
%	7.7	2.6	0.4	9.5	20.4	33.3	13.5	12.7		

WINTER 1983/4

	DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
1	*			3	7	21!	1	4	4	2	4	8	-*-		
2	*			3	6	18!	1	4	4	2	6	12	--*--		
3	*			1	9	9	1	4	4	1	4	4	-*-		
4	RAIN			--*--			2	7	14	*			-*-		
5	-*-			--*--			2	5	10	*			*		
6	*			1	5	5	3	7	21!	*			1	3	3
7	-*-			2	6	12	2	8	16!	*			1	2	2
8	RAIN			1	6	6	1	7	7	*			--*--		
9	1	6	6	1	6	6	--*--			*			1	2	2
10	--*--			RAIN			*			1	2	2	1	4	4
11	1	4	4	2	6	12	*			1	3	3	--*--		
12	--*--			3	6	18!	*			-*-			--*--		
13	RAIN			2	8	16!	*			1	3	3	*		
14	--*--			2	7	14	-*-			--*--			*		
15	1	5	5	1	6	6	-*-			1	3	3	1	4	4
16	1	4	4	4	6	24!	-*-			--*--			--*--		
17	1	5	5	1	4	4	-*-			-*-			1	3	3
18	2	5	10	2	5	10	-*-			-*-			*		
19	3	5	15!	--*--			-*-			-*-			*		
20	3	5	15!	--*--			2	7	14	--*--			*		
21	2	5	10	6	5	30!	3	5	15!	--*--			*		
22	1	4	4	1	6	6	2	5	10	--*--			*		
23	1	4	4	4	7	28!	1	3	3	5	5	25!	*		
24	3	5	15!	--*--			-*-			7	7	49!	*		
25	--*--			--*--			--*--			2	6	12	*		
26	RAIN			1	4	4	-*-			2	7	14	*		
27	RAIN			1	3	3	-*-			1	5	5	*		
28	*			1	6	6	-*-			1	5	5	*		
29	RAIN			--*--			-*-			--*--			*		
30	RAIN			--*--			-----			1	3	3	*		
31	RAIN			--*--			-----			--*--			-----		
TOTAL			97			258			122			148			18

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	0	33	45	0	10	5	0	4	97	15.1
JANUARY	6	10	0	118	8	75	35	6	258	40.1
FEBRUARY	0	0	18	24	18	30	32	0	122	19.0
MARCH	0	14	105	0	4	10	0	15	148	23.0
APRIL	0	0	3	0	0	7	4	4	18	2.8
TOTAL	6	57	171	142	40	127	71	29	643	
%	0.9	8.9	26.6	22.1	6.2	19.8	11.0	4.5		

WINTER 1984/5

	DECEMBER			JANUARY			FEBRUARY			MARCH			APRIL		
1	2	5	10	1	6	6	3	7	21!	-*-			RAIN		
2	--*--			1	4	4	--*--			-*-			RAIN		
3	-*-			1	3	3	*			2	4	8	RAIN		
4	RAIN			1	2	2	*			1	4	4	RAIN		
5	RAIN			1	3	3	*			*			RAIN		
6	RAIN			2	3	6	-*-			RAIN			RAIN		
7	RAIN			-*-			-*-			*			RAIN		
8	1	6	6	--*--			-*-			*			2	4	8
9	*			-*-			--*--			RAIN			1	3	3
10	*			-*-			--*--			*			1	4	4
11	*			-*-			-*-			*			-*-		
12	*			-*-			-*-			*			1	5	5
13	*			-*-			-*-			-*-			RAIN		
14	RAIN			-*-			-*-			-*-			*		
15	1	4	4	1	2	2	-*-			2	3	6	RAIN		
16	2	3	6	3	3	9	-*-			1	3	3	*		
17	2	6	12	4	5	20!	-*-			-*-			*		
18	--*--			--*--			--*--			--*--			RAIN		
19	1	7	7	-*-			--*--			--*--			RAIN		
20	--*--			-*-			-*-			--*--			1	5	5
21	--*--			3	5	15!	-*-			--*--			*		
22	*			5	7	35!	RAIN			-*-			*		
23	RAIN			1	8	8	*			1	5	5	*		
24	-*-			--*--			*			1	3	3	RAIN		
25	1	6	6	--*--			*			1	3	3	-*-		
26	-*-			-*-			*			1	2	2	RAIN		
27	--*--			-*-			*			1	4	4	1	4	4
28	-*-			-*-			*			1	4	4	1	4	4
29	--*--			--*--			-----			2	3	6	RAIN		
30	-*-			RAIN			-----			1	2	2	*		
31	1	5	5	RAIN			-----			1	4	4	-----		
TOTAL			56			113			21			54			33

SUMMARY	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	TOTAL	%
DECEMBER	4	0	0	18	22	7	5	0	56	20.2
JANUARY	8	0	44	0	2	0	53	6	113	40.8
FEBRUARY	0	0	0	0	0	21	0	0	21	7.6
MARCH	4	8	13	0	0	11	8	10	54	19.5
APRIL	0	15	0	0	10	0	0	8	33	11.9
TOTAL	16	23	57	18	34	39	66	24	277	
%	5.8	8.3	20.6	6.5	12.3	14.1	23.8	8.7		

APPENDIX 5: SNOWDRIFT VALUES FOR EACH SITE FOR THE WINTERS 1954/5 TO 1983/4.

There are three parts to this appendix. The first (A) lists the directions for which the source of the stream at each site is leeward and the mean and standard deviation (S.D.) of the 30 values for each site. Site 1, for example, is leeward to winds from the NNE, ENE, ESE, SSE and SSW. The second (B) lists the value of snowdrift (as a percentage of the maximum possible: 100%) for each site for each winter. The method used to calculate snowdrift was described in section 4.5.1. The name of each site is listed in Appendix 1. The third (C) plots five-year moving averages of snowdrift for the eight main wind directions. The results are analysed briefly in section 4.5.2.

A: Directions for which each site is leeward.

	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	Mean	S.D.
1,23	*	*	*	*	*				55.7	16.4
2,8,36,46,49	*	*	*	*					43.1	16.3
3,9,50		*	*	*					38.7	16.5
4,5,12,38,42		*	*	*	*				51.2	16.9
6,20,28,31,54					*	*	*	*	56.9	16.3
7,13			*	*	*	*	*		74.7	11.6
10			*	*					28.7	14.6
11	*	*	*	*	*	*			76.3	12.5
14					*	*	*	*	62.6	13.8
15,19,41,53			*	*	*	*			61.2	13.9
16			*	*	*				41.1	15.0
17,27,44	*				*	*	*	*	61.8	16.3
18		*	*	*				*	49.8	12.9
21,29,30						*	*	*	44.8	16.7
22	*	*	*					*	37.7	13.5
24,25,26,52					*	*	*		45.8	13.4
32	*	*	*						26.9	13.7
33,40,48	*					*	*	*	48.8	16.8
34,43	*	*				*	*	*	58.9	15.0
35	*	*	*			*	*	*	71.0	13.9
37				*	*	*			46.8	13.8
39,47		*	*	*	*	*			71.2	13.9
45	*					*		*	35.9	13.7
51	*						*	*	28.7	13.6

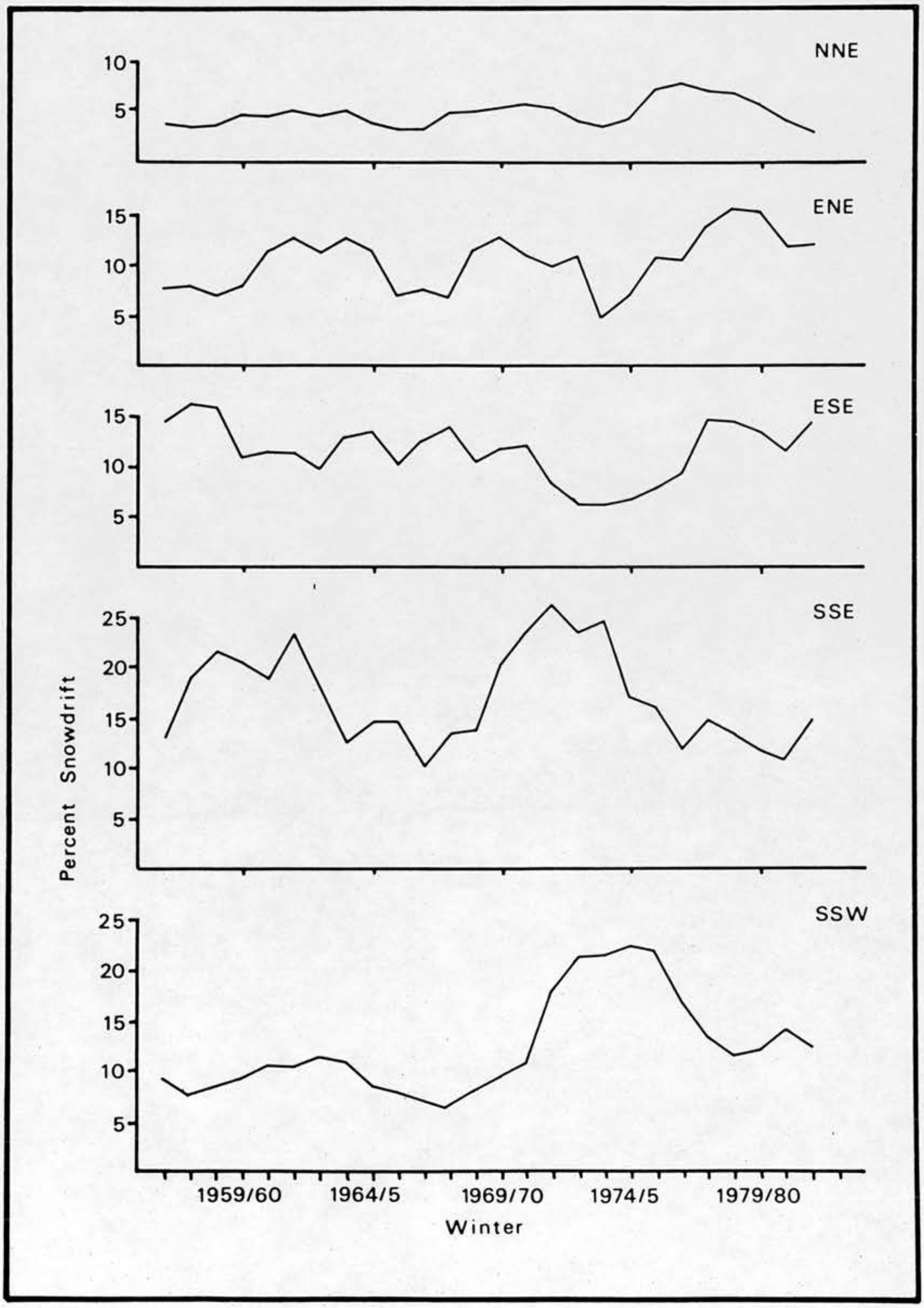
B: Value of snowdrift for each site.

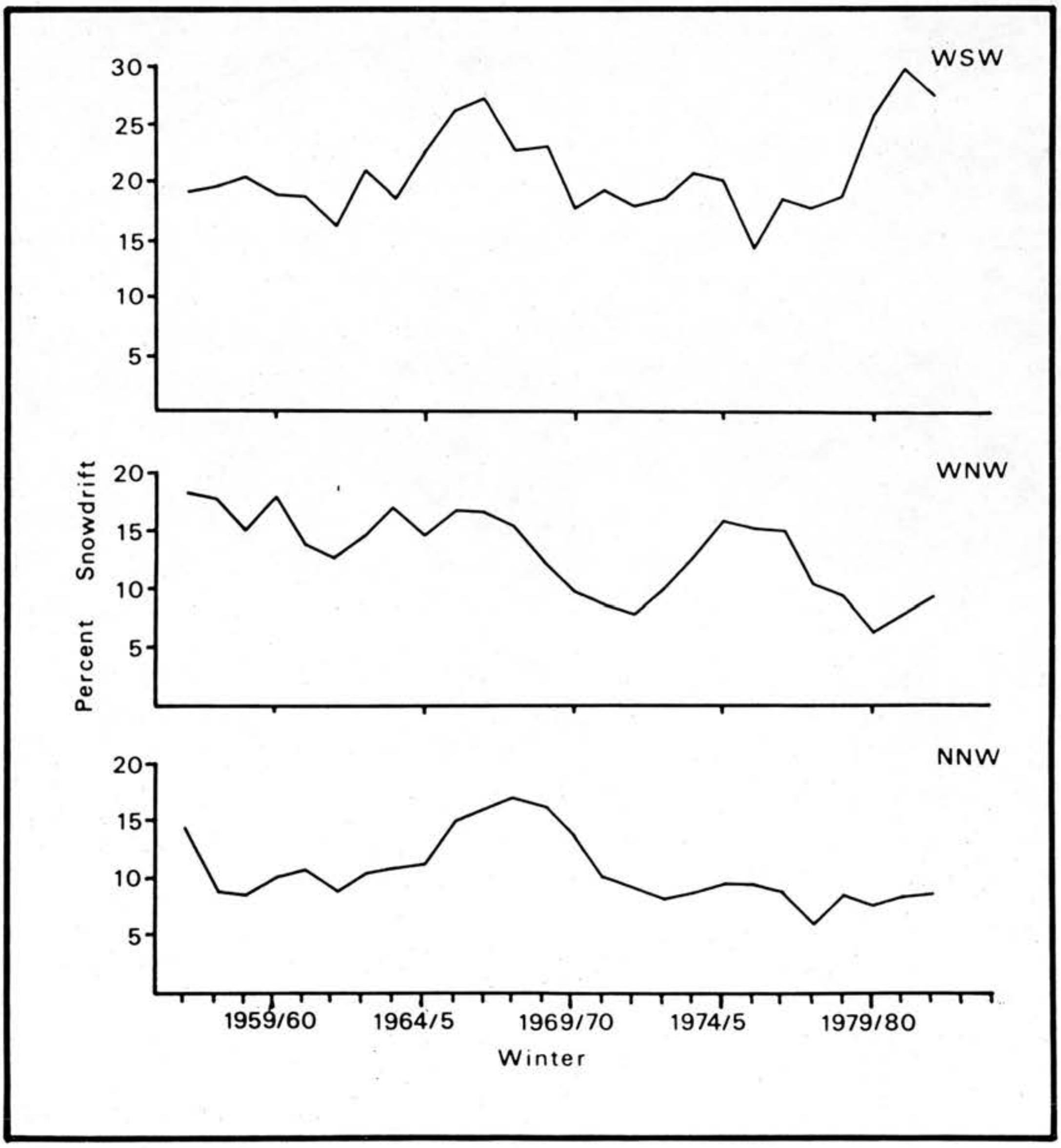
Sites	54/5	55/6	56/7	57/8	58/9	59/0	60/1	61/2	62/3	63/4
1,23	40.1	44.2	66.0	49.2	41.0	70.2	55.6	49.2	68.0	70.0
2,8,36,46,49	27.5	38.9	52.2	45.1	31.0	66.4	45.7	30.8	58.0	60.8
3,9,50	19.4	37.2	50.0	39.9	29.8	58.8	43.6	23.1	53.3	56.9
4,5,12,38,42	32.0	42.5	63.8	44.0	39.8	62.6	53.5	41.5	63.3	66.1
6,20,28,31,54	72.6	61.1	47.9	54.9	69.0	33.6	54.3	69.2	41.9	39.3
7,13	45.3	84.4	91.0	73.3	76.4	73.8	90.1	73.1	53.2	76.5
10	8.5	32.5	47.0	26.4	23.2	47.6	43.6	15.8	21.6	43.8
11	45.3	68.9	86.3	65.3	68.8	78.9	83.6	62.6	83.3	84.4
14	41.5	70.0	69.0	55.2	65.2	60.7	78.2	72.7	32.9	66.2
15,19,41,53	26.3	62.5	81.1	46.6	61.0	60.1	81.5	47.6	46.9	67.4
16	21.1	37.8	60.8	30.5	33.2	51.4	53.5	34.2	31.6	53.0
17,27,44	80.7	62.8	50.1	60.1	70.2	41.2	56.4	76.9	46.6	43.2
18	55.2	46.4	53.9	47.9	45.6	66.2	51.4	35.0	63.6	63.4
21,29,30	60.0	55.8	34.1	50.8	59.0	29.8	54.3	50.8	31.9	30.1
22	58.6	30.0	34.1	44.8	34.8	39.2	21.8	27.3	67.0	34.0
24,25,26,52	36.8	51.9	44.0	46.9	53.2	26.2	46.5	57.3	31.6	32.8
32	21.8	20.8	30.2	36.8	19.0	31.8	14.0	15.4	56.7	27.5
33,40,48	68.1	57.5	36.3	56.0	60.2	37.4	46.5	58.5	36.6	34.0
34,43	79.0	62.2	39.3	69.5	66.8	48.6	46.5	65.8	68.3	47.1
35	82.8	76.6	64.3	87.6	78.0	61.6	58.4	66.2	88.6	57.6
37	22.5	48.1	56.1	28.5	49.8	47.1	69.6	47.2	26.6	56.9
39,47	37.2	67.2	84.1	60.1	67.6	71.3	81.5	54.4	78.6	80.5
45	49.1	35.6	26.4	29.3	44.8	23.7	37.9	33.0	30.3	24.8
51	62.9	32.8	16.0	39.9	32.4	28.7	18.5	45.1	21.3	19.6

Sites	64/5	65/6	66/7	67/8	68/9	69/0	70/1	71/2	72/3	73/4
1,23	29.2	53.4	35.5	29.6	58.9	53.8	70.4	90.0	89.9	82.9
2,8,36,46,49	20.1	46.1	29.7	22.9	55.3	46.9	54.7	76.7	25.6	43.2
3,9,50	14.9	42.0	28.1	15.4	50.1	34.3	49.3	72.7	23.7	40.5
4,5,12,38,42	24.0	49.3	33.9	22.1	53.7	40.9	65.0	86.0	38.0	80.2
6,20,28,31,54	79.9	53.8	70.3	77.1	44.7	53.1	45.2	23.8	74.5	56.8
7,13	75.9	78.8	84.1	55.8	65.2	68.4	57.3	87.4	88.4	78.5
10	9.4	34.7	26.9	4.9	33.5	34.3	18.6	65.8	23.7	29.5
11	63.1	68.5	71.6	61.8	78.4	65.7	86.7	97.7	80.1	95.1
14	71.7	50.5	81.5	54.3	42.3	56.1	46.4	79.6	83.8	81.2
15,19,41,53	52.4	57.1	68.8	49.1	56.6	53.1	50.8	86.8	78.2	81.4
16	18.5	42.0	32.7	11.6	37.1	41.2	34.5	79.1	38.0	69.2
17,27,44	85.1	57.9	71.9	84.6	49.9	65.7	50.6	27.8	76.4	59.5
18	28.3	51.8	41.2	41.6	63.1	53.3	55.9	74.4	33.4	41.3
21,29,30	70.8	46.5	64.5	70.4	41.1	46.2	29.5	10.5	60.2	17.1
22	28.3	49.4	18.5	45.7	57.1	43.9	53.5	20.9	16.3	18.8
24,25,26,52	66.5	43.0	57.2	50.9	31.7	34.1	38.6	22.1	64.8	56.0
32	14.9	39.6	5.4	19.5	44.7	24.9	46.9	19.2	6.6	18.0
33,40,48	76.0	50.6	66.1	77.9	46.3	58.8	34.9	14.5	62.1	19.8
34,43	81.5	57.9	67.3	88.4	62.9	58.8	65.6	21.4	62.1	30.8
35	85.7	86.1	69.9	89.9	85.8	71.1	76.4	29.7	66.8	35.1
37	48.2	28.9	66.2	42.3	33.7	40.8	39.8	22.1	53.5	77.1
39,47	57.9	64.4	70.0	54.3	73.2	53.1	81.3	93.7	68.5	92.4
45	52.5	29.0	50.8	65.9	37.7	43.5	28.3	13.4	51.8	15.7
51	42.1	35.5	30.0	45.7	26.8	46.9	18.6	6.8	21.9	7.6

Sites	74/5	75/6	76/7	77/8	78/9	79/0	80/1	81/2	82/3	83/4
1,23	43.8	44.7	73.6	71.4	72.9	82.8	31.2	56.5	40.6	64.7
2,8,36,46,49	19.9	29.7	54.5	60.3	52.1	75.3	25.9	35.3	20.2	58.5
3,9,50	14.1	27.0	47.0	43.9	23.6	73.5	24.4	33.8	12.5	57.6
4,5,12,38,42	38.0	42.0	66.1	55.0	71.2	81.0	29.7	55.0	32.9	63.8
6,20,28,31,54	80.0	69.4	45.5	39.8	47.8	24.8	74.1	64.7	79.9	41.5
7,13	75.5	87.3	70.2	54.9	75.1	75.5	66.2	81.4	77.0	85.7
10	9.5	27.0	29.1	24.3	36.8	52.0	15.0	17.8	9.9	48.7
11	59.9	70.5	78.0	84.3	87.8	95.3	62.8	96.1	73.9	84.5
14	73.4	72.9	59.9	44.2	48.7	46.6	57.6	75.9	76.7	59.1
15,19,41,53	49.5	67.8	52.6	48.3	72.5	72.0	51.9	78.6	63.6	74.7
16	33.4	42.0	48.2	35.4	57.6	59.5	20.3	39.0	30.3	54.9
17,27,44	85.8	72.1	53.0	56.2	54.3	26.6	75.6	66.2	87.6	42.4
18	28.2	37.0	51.4	53.0	59.9	74.7	47.3	34.9	25.2	62.1
21,29,30	56.1	54.4	26.4	28.7	27.0	17.3	68.8	43.5	59.5	35.3
22	26.5	26.2	40.1	55.9	51.2	53.5	42.4	24.1	33.4	40.9
24,25,26,52	65.9	59.4	41.1	30.7	38.3	23.6	51.2	63.6	67.2	36.0
32	12.4	16.2	35.7	46.8	41.7	52.3	19.5	23.0	10.7	36.4
33,40,48	61.9	58.1	33.9	45.1	28.7	19.1	70.3	45.0	67.2	36.2
34,43	66.5	58.1	51.8	64.7	42.3	40.6	79.7	61.0	69.8	45.1
35	68.5	71.6	62.1	75.5	68.7	69.6	88.3	66.5	70.2	71.7
37	47.5	54.3	42.3	37.5	46.1	43.0	43.3	73.1	63.2	48.1
39,47	54.1	67.8	70.5	67.9	86.1	93.5	61.3	94.6	66.2	83.6
45	36.0	38.5	16.3	52.2	26.1	15.5	56.0	42.2	53.7	25.2
51	45.8	31.3	29.5	32.2	12.9	6.6	38.7	5.4	33.9	16.4

C. Five-year moving averages of snowdrift.





WSW
WNW
NNW
Percent Snowdrift
30
25
20
15
10
5
20
15
10
5
20
15
10
5
1959/60
1964/5
1969/70
1974/5
1979/80
Winter

APPENDIX 6: WIND-DRIFT VALUES FOR EACH SITE FOR THE WINTERS 1954/5 TO 1983/4.

There are two parts to this appendix. The first (A) lists the direction of the fetch at each site and the mean and standard deviation (S.D.) of the 30 values for each site. Site 1, for example, has a fetch to the ESE, SSE, SSW and WSW. The second (B) lists the value of wind-drift (as a percentage of the maximum possible: 100%) for each site for each winter. The method for the calculation of wind-drift was described in section 4.6.1. The name of each site is listed in Appendix 1.

A: Direction of the fetch.

	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	Mean	S.D.
1,41			*	*	*	*			64.5	22.2
2,8,42	*	*	*	*					37.6	24.1
3,4	*	*	*	*	*				55.1	23.8
5,47		*	*	*		*			52.5	24.2
6,40				*	*	*	*	*	81.9	18.4
7		*	*	*		*	*		79.5	18.2
9,51		*	*						14.7	17.3
10,19,24				*					19.6	19.2
11	*	*			*	*			44.3	21.7
12	*			*		*			41.1	25.8
13,30					*	*	*	*	62.2	23.9
14,33,52					*	*	*		51.9	22.5
15					*				19.6	19.2
16	*	*	*	*		*			55.8	25.0
17	*			*	*	*	*	*	85.2	17.3
18,26,43					*			*	27.9	21.9
20,54						*		*	28.6	19.2
21,46		*							5.4	10.2
22,34	*	*		*		*	*	*	72.1	20.5
23	*		*	*	*	*		*	78.5	19.7
25						*			18.2	17.6
27				*	*	*	*		71.5	18.8
28	*	*		*			*	*	54.9	22.2
29	*				*	*	*		55.2	21.7
31	*	*			*	*	*	*	71.1	20.4
32,39		*	*	*					34.3	22.9
34	*	*				*	*	*	53.5	22.1
35		*	*	*			*	*	60.9	22.0
36	*	*		*					28.6	22.1
37		*			*	*			41.0	22.4
38			*	*	*				46.4	22.1
44					*		*		33.7	22.2
45	*	*			*			*	36.5	21.8
48		*				*			23.6	17.9
49		*	*	*	*				52.3	24.4
50		*		*	*	*			60.6	23.5
53					*	*			35.6	22.6

B: Value of wind-drift for each site

Sites	54/5	55/6	56/7	57/8	58/9	59/0	60/1	61/2	62/3	63/4
1,41	89.3	85.2	93.0	48.6	74.8	83.5	37.2	18.3	67.3	86.7
2,8,42	35.7	78.5	4.6	10.6	46.8	60.1	27.7	11.2	37.1	53.7
3,4	48.5	78.5	56.8	47.8	57.2	61.1	30.9	11.2	79.1	69.2
5,47	78.4	87.9	40.8	14.8	64.4	83.7	34.0	20.5	45.3	76.4
6,40	96.5	89.6	95.6	89.3	85.0	67.2	94.8	97.5	63.1	91.8
7	87.2	99.9	48.0	62.7	89.6	99.9	86.5	99.9	58.3	84.2
9,51	3.5	10.3	4.6	10.6	15.0	32.8	4.9	2.2	37.1	7.9
10,19,24	32.2	68.2	0.0	0.0	31.8	27.3	22.8	9.0	0.0	45.8
11	57.4	12.1	88.4	44.8	28.0	25.8	9.5	11.5	70.2	43.4
12	74.9	77.6	36.2	4.2	49.4	50.9	29.1	18.3	8.2	68.5
13,30	64.2	21.4	95.6	89.3	53.2	39.9	72.0	88.8	63.1	46.0
14,33,52	61.0	16.3	93.4	43.6	33.6	28.1	64.4	70.3	57.6	41.5
15	32.2	68.2	0.0	0.0	31.8	27.3	22.8	9.0	0.0	45.8
16	78.4	87.9	40.8	14.8	64.4	83.7	34.0	20.5	45.3	76.4
17	96.5	89.6	95.6	89.3	85.0	67.2	94.8	97.8	63.1	91.8
18,26,43	16.0	5.1	54.4	82.9	30.0	12.8	10.8	18.2	47.5	20.0
20,54	45.9	14.5	38.4	49.9	37.2	35.4	13.9	27.5	13.7	27.2
21,46	1.9	2.7	0.0	3.4	0.0	1.2	0.0	2.2	20.0	5.2
22,34	85.5	92.3	43.4	55.5	74.6	67.4	91.6	99.7	41.1	81.5
23	92.6	90.3	95.2	94.3	94.4	95.3	44.8	36.5	81.0	91.2
25	42.7	9.4	36.2	4.2	17.6	23.6	6.3	9.3	8.2	22.7
27	93.2	84.5	93.4	43.6	65.4	55.4	87.2	79.3	57.6	87.3
28	42.8	82.9	7.2	51.3	57.0	43.8	85.3	90.7	32.9	58.9
29	61.0	16.3	93.4	43.6	33.6	28.1	64.4	70.6	57.6	41.5
31	66.1	24.1	95.6	96.8	53.2	41.1	72.0	90.7	83.1	51.2
32,39	35.7	78.5	4.6	10.6	46.8	60.1	27.7	11.2	37.1	53.7
34	53.3	24.1	43.4	55.5	42.8	40.1	68.8	91.0	43.1	35.7
35	44.4	90.5	11.8	58.5	72.0	75.4	90.2	88.2	50.0	61.5
36	34.1	70.9	0.0	3.4	31.8	28.5	22.8	11.2	20.0	51.0
37	57.4	12.1	88.4	44.8	28.0	25.8	9.5	11.5	70.2	43.4
38	46.6	75.8	56.8	44.4	57.2	59.9	30.9	9.0	59.1	64.0
44	18.3	6.9	57.2	39.4	16.0	4.5	58.1	61.0	49.4	18.8
45	17.9	7.8	54.4	86.3	30.0	14.0	10.8	20.4	67.5	25.2
48	44.6	12.1	36.2	7.6	17.6	24.8	6.3	11.5	28.2	27.9
49	48.5	78.5	56.8	47.8	57.2	61.1	30.9	11.2	79.1	69.2
50	89.6	80.3	88.4	44.8	59.8	53.1	32.3	20.5	70.2	89.2
53	55.5	9.4	88.4	41.4	28.0	24.6	9.5	9.3	50.2	38.2

Sites	64/5	65/6	66/7	67/8	68/9	69/0	70/1	71/2	72/3	73/4
1,41	34.5	50.4	38.4	37.1	53.9	81.9	84.1	82.5	85.4	87.8
2,8,42	51.5	53.4	11.7	13.2	32.6	30.8	58.8	31.4	42.8	14.7
3,4	52.7	53.4	22.5	19.5	33.2	67.0	62.9	84.6	77.6	81.2
5,47	41.1	64.6	32.4	30.6	55.8	45.7	82.7	32.3	53.9	22.7
6,40	51.6	46.5	91.9	93.6	90.4	75.8	88.9	96.1	96.8	98.4
7	64.8	99.9	89.1	93.3	98.6	62.1	87.5	46.8	65.3	33.3
9,51	14.4	53.4	8.0	6.4	8.8	22.5	2.7	3.9	3.3	1.4
10,19,24	3.4	0.0	3.7	6.8	23.1	6.8	47.8	27.5	39.5	13.3
11	66.0	25.4	36.3	23.9	27.7	54.1	47.3	57.1	49.2	75.9
12	60.4	11.2	24.4	24.2	47.7	24.7	88.3	28.4	50.6	21.3
13,30	48.2	46.5	88.2	86.6	67.3	69.0	41.1	68.6	57.3	85.1
14,33,52	48.2	46.5	87.1	60.7	43.1	54.1	44.1	68.6	56.1	74.5
15	3.4	0.0	3.7	6.8	23.1	6.8	47.8	27.5	39.5	13.3
16	74.8	64.6	32.4	30.6	56.5	47.2	91.0	32.3	53.9	22.7
17	85.3	46.5	91.9	93.4	91.1	77.3	97.2	96.1	96.8	98.4
18,26,43	1.2	0.0	11.9	32.4	24.8	51.1	4.1	53.2	36.0	77.1
20,54	23.3	11.2	21.8	43.3	48.1	31.3	32.2	0.9	12.3	18.6
21,46	7.8	14.2	4.8	0.0	2.5	0.0	2.7	3.0	3.3	1.4
22,34	92.2	60.7	86.0	87.1	93.0	41.1	95.8	45.9	65.3	33.3
23	68.5	50.4	39.6	63.2	78.8	98.3	92.4	82.5	86.6	98.4
25	23.3	11.2	20.7	17.4	23.9	16.4	32.2	0.9	11.1	8.0
27	51.6	46.5	90.8	67.7	66.2	60.9	88.9	96.1	95.6	87.8
28	68.6	49.5	65.2	69.5	69.1	24.7	63.6	45.0	54.2	25.3
29	81.9	46.5	87.1	60.7	43.8	54.6	49.4	68.6	56.1	74.5
31	89.7	60.7	93.0	86.6	70.5	70.5	52.1	71.6	60.6	86.5
32,39	17.8	53.4	11.7	13.2	31.9	29.3	50.5	31.4	42.8	14.7
34	88.5	60.7	82.2	80.1	69.9	34.3	48.0	18.4	25.5	20.0
35	41.5	88.7	68.2	75.9	74.7	45.7	55.3	45.9	54.2	25.3
36	44.9	14.2	8.5	6.8	26.3	8.3	58.8	30.5	42.8	14.7
37	32.3	25.4	35.3	23.9	27.0	52.6	39.0	57.1	49.2	75.9
38	11.2	39.2	17.7	19.7	30.0	65.5	51.9	81.6	74.3	79.8
44	24.9	35.3	66.4	43.3	19.2	37.7	8.9	67.7	45.0	66.5
45	42.7	14.2	16.7	32.4	28.0	52.6	15.1	56.2	39.3	78.5
48	31.1	25.4	25.5	17.4	26.4	16.4	34.9	3.9	14.4	9.4
49	19.0	53.4	22.5	19.7	32.5	81.9	54.6	84.6	77.6	81.2
50	35.7	25.4	40.0	31.2	50.1	59.4	86.8	84.6	88.7	89.2
53	24.5	11.2	31.5	23.9	24.5	52.6	36.3	53.1	45.9	74.5

Sites	74/5	75/6	76/7	77/8	78/9	79/0	80/1	81/2	82/3	83/4
1,41	50.0	91.3	62.4	81.2	65.6	36.1	62.8	60.8	22.6	83.5
2,8,42	1.6	19.0	37.2	71.6	59.4	81.2	61.5	78.2	7.9	4.1
3,4	40.6	21.0	70.0	71.6	84.5	86.3	68.4	83.9	16.3	14.2
5,47	11.7	91.4	33.9	82.9	58.7	84.0	60.9	55.1	14.2	74.0
6,40	99.1	89.2	88.1	87.1	50.5	38.1	44.1	69.8	92.9	97.8
7	60.8	96.4	60.6	88.3	72.0	94.1	87.6	65.5	84.5	89.3
9,51	0.7	9.2	5.3	11.2	46.6	61.1	50.4	1.2	0.0	1.6
10,19,24	0.9	8.4	25.0	58.7	10.1	19.5	5.8	48.8	0.8	2.2
11	49.8	79.3	47.6	16.4	48.0	62.1	21.9	39.0	28.9	81.2
12	11.0	83.6	35.5	73.4	14.8	23.5	15.8	82.1	21.3	72.4
13,30	98.2	81.8	63.1	28.4	40.4	18.6	38.3	21.0	92.1	95.6
14,33,52	91.6	80.8	45.2	15.8	32.5	13.9	36.3	12.8	55.7	80.8
15	0.9	8.4	25.0	58.7	10.1	19.5	5.8	48.8	0.8	2.2
16	11.7	92.8	40.8	84.6	61.4	84.6	66.2	83.3	21.3	74.3
17	98.2	90.6	95.0	88.8	53.2	38.7	49.4	98.2	99.9	98.1
18,26,43	45.6	2.0	50.7	12.6	33.0	9.8	8.9	14.1	44.8	24.9
20,54	17.7	73.8	21.5	25.6	9.9	8.1	6.7	13.5	49.8	85.0
21,46	0.7	2.1	4.3	1.7	18.2	53.0	5.0	0.0	0.0	0.6
22,34	60.8	90.9	66.5	90.5	46.3	86.6	47.5	93.1	91.6	88.6
23	56.6	92.9	87.2	95.5	73.5	41.4	70.1	98.0	66.1	98.6
25	10.1	73.8	3.6	13.0	2.0	3.4	4.7	5.1	13.4	70.2
27	92.5	89.2	70.2	74.5	42.6	33.4	42.1	61.4	56.5	83.0
28	50.7	16.9	62.9	77.5	44.2	83.3	42.8	86.8	78.2	18.4
29	91.6	83.2	52.1	17.5	35.2	14.5	41.6	41.0	62.8	81.1
31	98.9	84.3	74.3	31.8	61.3	71.6	48.6	49.4	99.2	96.5
32,39	1.6	17.6	30.3	69.9	56.7	80.6	56.2	50.0	0.8	1.0
34	59.9	82.3	41.5	31.8	36.2	67.1	41.7	43.7	90.8	86.4
35	50.7	22.6	57.0	85.3	70.0	90.9	82.9	60.4	71.1	19.1
36	1.6	11.9	36.2	62.1	31.0	73.1	16.1	77.0	7.9	11.0
37	49.8	77.9	40.7	14.7	45.3	61.5	16.6	10.6	21.8	80.9
38	39.9	17.5	58.8	68.2	63.6	32.7	58.1	55.7	9.2	13.3
44	81.5	7.0	41.6	2.8	30.5	10.5	31.6	7.7	42.3	10.6
45	46.3	5.5	61.9	16.0	53.9	63.4	19.2	42.3	51.9	25.8
48	10.8	75.9	7.9	14.7	20.2	56.4	9.7	7.1	13.4	70.8
49	40.6	19.6	63.1	69.9	81.8	85.7	63.1	55.7	9.2	13.9
50	50.7	86.3	65.7	73.4	55.4	81.0	22.4	59.6	22.6	83.1
53	49.1	75.8	36.4	13.0	27.1	8.5	11.6	10.8	21.8	80.3

APPENDIX 7: DATA ON THE MORPHOLOGY OF SITES AND THE EXTENT OF SNOWCOVER AT THOSE SITES.

The data listed below are used in the multivariate analysis of the morphology of sites in Chapters 5, 6 and 7. The name of each site is listed in Appendix 1.

A Global radiation (langleys)
B Basin ratio
C Gully side slope (degrees)
D Form ratio
E Fetch (metres)
F Top altitude (metres)
G Topographic rise (metres)
H Leeward slope (metres)
I Snowdrift (percent)
J Wind-drift (percent)
K Topographic exposure (degrees)

Site	A	B	C	D	E	F	G	H	I	J	K
1	358.09	0.131	13.3	0.52	2150	958	1026	2494	55.7	64.5	42
2	423.91	0.103	14.2	0.56	2325	960	1036	1700	43.1	37.6	106
3	376.72	0.145	16.8	0.26	4350	1018	942	1837	38.7	55.1	68
4	342.97	0.136	24.7	0.36	3575	890	856	2544	51.2	55.1	72
5	343.84	0.067	21.3	0.47	3450	870	871	2300	51.2	52.5	118
6	384.27	0.218	10.3	0.47	2575	1003	862	1694	56.9	81.9	130
7	306.29	0.107	23.5	0.54	2650	907	777	2112	74.7	79.5	110
8	367.07	0.140	16.5	0.53	2325	1208	1315	1369	43.1	37.6	122
9	306.28	0.113	24.3	0.09	0	992	1094	2506	38.7	14.7	138
10	333.24	0.054	10.8	0.11	0	815	1010	2681	28.7	19.6	176
11	386.25	0.206	12.4	0.32	1900	991	777	2594	76.3	44.3	67
12	374.12	0.033	13.8	0.21	1785	965	791	2406	51.2	41.1	128
13	353.95	0.128	15.0	0.36	2250	982	801	2862	74.7	62.2	90
14	355.44	0.048	6.8	0.18	1100	1052	801	2675	62.6	51.9	147
15	363.75	0.124	14.2	0.28	900	938	687	2100	61.2	19.6	132
16	333.95	0.107	18.4	0.21	2550	1097	599	2169	41.1	55.8	66
17	386.35	0.083	11.5	0.46	2700	1145	1046	2762	61.8	85.2	108
18	331.02	0.133	7.9	0.52	1100	1006	970	2844	49.8	27.9	120
19	293.14	0.100	5.9	0.14	500	1021	1025	2575	61.4	19.6	172
20	393.78	0.050	11.7	0.22	1150	1045	1031	2756	56.9	28.6	172
21	392.98	0.100	10.2	0.19	1350	1065	1094	2481	44.8	5.4	150
22	461.35	0.160	12.5	0.29	3975	1232	1116	3004	37.7	72.1	81
23	395.16	0.118	17.1	0.49	3625	1268	1227	3087	55.7	78.5	115
24	311.64	0.075	9.8	0.31	1000	975	1089	3338	45.8	19.6	180
25	327.22	0.057	22.4	0.21	0	1050	1129	3387	45.8	18.2	162
26	419.07	0.100	11.0	0.15	0	805	1003	3606	45.8	27.9	180
27	373.19	0.152	9.3	0.39	2600	975	1004	2370	61.8	71.5	137
28	431.60	0.192	11.0	0.35	2775	988	1061	3444	56.9	54.9	94
29	382.26	0.044	6.9	0.18	2275	991	960	3737	44.8	55.2	180
30	361.91	0.070	12.6	0.27	2150	948	976	3737	44.8	62.3	170
31	401.62	0.121	15.0	0.58	5850	841	871	2262	56.9	71.1	82
32	487.62	0.300	21.5	0.31	1925	919	846	3175	26.9	34.3	66
33	463.34	0.156	21.3	0.22	350	867	819	3612	48.8	51.8	138
34	474.28	0.150	18.2	0.22	3250	991	946	3375	58.9	53.5	74
35	458.67	0.120	16.6	0.19	3850	1075	1003	3094	71.0	60.9	46
36	443.98	0.082	18.6	0.36	3150	1082	1012	2731	43.1	28.6	48
37	352.39	0.070	11.7	0.20	2125	1073	1022	2700	46.8	41.0	121
38	375.10	0.124	16.8	0.34	2650	937	1051	3219	51.2	46.4	70

	A	B	C	D	E	F	G	H	I	J	K
39	379.86	0.133	15.2	0.61	1150	844	1005	3150	71.2	34.3	58
40	431.24	0.125	13.8	0.59	2000	801	952	3125	48.8	81.8	72
41	378.69	0.107	15.0	0.48	2700	838	951	2881	61.4	64.5	58
42	378.73	0.147	9.1	0.14	2300	829	994	2900	51.2	35.4	90
43	447.05	0.130	21.3	0.23	300	895	972	2212	58.9	27.9	30
44	425.71	0.090	13.3	0.42	950	859	990	2512	61.8	33.7	80
45	456.55	0.172	12.5	0.27	1825	900	974	2719	35.9	36.5	77
46	311.23	0.213	27.2	0.51	875	892	944	3081	43.1	5.4	30
47	345.09	0.118	22.9	0.41	1525	850	1017	2981	70.3	52.5	63
48	471.30	0.016	16.6	0.42	1100	887	1060	2581	48.8	23.6	150
49	421.67	0.054	14.7	0.38	2225	950	961	2506	38.7	52.3	143
50	377.68	0.062	10.6	0.38	2800	964	974	2937	51.2	60.6	83
51	515.24	0.100	8.7	0.15	375	1012	1065	2919	28.7	14.7	157
52	392.71	0.065	8.5	0.19	1000	978	976	2275	45.8	51.8	137
53	356.75	0.081	18.8	0.30	1000	918	841	2162	61.4	35.6	69
54	404.40	0.103	12.5	0.49	700	828	981	2650	56.9	28.6	91

EXTENT OF SNOWCOVER

These data are the length of snowcover in a gully expressed as a percentage of its length and were measured from aerial photographs (A,B,C and E) and a Landsat scene (D) and used in the regression analyses in Chapter 7.

A 18.4.55 C 25.4.68 E 13.4.81
B 1.4.65 D 20.4.76

	A	B	C	D	E		A	B	C	D	E
1	86.2	75.8	----	60.0	22.5	22	50.8	87.5	----	69.0	59.7
2	42.9	63.4	----	37.0	4.1	23	92.9	97.5	----	63.0	63.6
3	94.7	71.8	----	44.0	24.6	24	----	----	----	24.0	38.6
4	----	86.8	----	66.0	62.5	25	85.0	99.9	----	55.0	88.5
5	59.2	72.4	----	63.0	56.6	26	56.0	----	----	56.0	37.3
6	62.9	96.3	----	57.0	17.3	27	55.0	70.3	----	67.0	28.8
7	83.7	92.5	----	48.0	25.0	28	47.0	72.3	----	56.0	30.3
8	82.7	87.5	----	67.0	39.6	29	60.9	94.3	----	59.0	46.9
9	----	85.5	----	44.0	69.7	30	87.3	95.0	----	46.0	36.4
10	----	73.7	----	43.0	41.1	31	64.0	83.1	----	34.0	29.1
11	35.7	79.9	----	39.0	21.0	32	73.7	84.2	66.3	48.0	17.1
12	30.8	61.3	----	34.0	30.4	33	86.6	96.3	78.1	42.0	52.1
13	97.5	92.8	----	54.0	----	34	92.1	99.9	74.7	39.0	38.6
14	51.8	52.9	----	23.0	----	35	92.3	80.8	85.7	65.0	46.3
15	78.7	64.1	----	48.0	----	36	78.3	67.9	64.7	54.0	51.9
16	----	84.1	----	78.0	----	37	----	99.9	65.6	91.5	----
17	85.0	99.9	----	82.0	54.1	38	----	62.3	10.0	25.5	----
18	62.8	85.0	----	77.0	53.6	39	----	----	10.0	16.3	----
19	65.1	65.0	----	43.0	37.0	40	----	86.2	6.5	----	----
20	----	82.7	----	76.0	50.3	41	----	61.7	3.8	14.0	----
21	64.7	83.1	----	82.0	46.9	42	----	56.3	15.9	----	----

	A	B	C	D	E		A	B	C	D	E
43	----	82.7	10.9	19.0	----	49	----	68.4	46.0	21.0	----
44	----	86.1	5.7	9.0	----	50	----	77.8	30.2	27.0	----
45	----	82.3	29.8	18.0	----	51	----	87.5	----	52.0	50.0
46	----	64.3	23.8	----	----	52	----	77.4	50.9	39.0	28.0
47	----	87.8	15.2	14.0	----	53	----	59.1	----	25.0	----
48	----	75.4	17.0	32.0	----	54	----	51.4	12.7	0.0	----

SITES USED IN CASE STUDIES

These sites were used in Chapter 9 to show some of the applications of the method.

	A	B	C	D	E	F	G	H	I	J	K
1	374.00	0.070	10.4	0.29	0	920	669	2437	56.7	37.6	115
2	333.90	0.095	8.1	0.44	1400	977	954	2266	50.0	41.0	115
3	353.68	0.141	22.5	0.42	3775	905	824	1331	50.0	69.3	40
4	359.65	0.088	22.9	0.25	2875	900	799	1663	50.0	37.0	63
5	459.73	0.127	17.5	0.30	3775	918	900	1806	50.2	44.0	46

For list of variables see top of Appendix.

1 Allt Coire an t-Sneachda
2 Coire Laogh Mor
3 Allt Uilleim
4 Allt Coire nan Cisteachan
5 Jeans Gully

APPENDIX 8: DEPTHS OF SNOW MEASURED IN APRIL 1984 AND APRIL 1985.

Left-hand column = mean depth of snow for each transect in April 1984; right-hand column = April 1985. Depths are in metres. Access was not possible to Allt Coolah in April 1985. Although Coire an t-Sneachda was not included in the original sample of 54 sites, it was used here because of ease of access. See Chapter 7 for further details. The location of each site is shown in Appendix 1.

COOLAH (40)			DUBHAIG (4)			LOCHAIN (14)			BHEAG (45)		
1	1.25	----	1	0.57	0.20	1	0.48	0.17	1	0.68	0.00
2	1.19	----	2	1.34	0.46	2	0.43	0.52	2	0.38	0.00
3	1.65	----	3	1.46	0.63	3	0.36	0.63	3	0.46	0.00
4	1.63	----	4	1.32	0.80	4	0.51	0.61	4	0.77	0.00
5	2.23	----	5	1.31	0.60	5	0.27	0.38	5	0.83	0.00
6	2.10	----	6	1.36	1.17	6	0.55	0.32	6	1.01	0.00
7	2.00	----	7	1.43	0.49	7	0.87	0.08	7	1.15	0.00
8	2.42	----	8	1.60	1.18	8	0.35	0.69	8	1.41	0.00
9	2.36	----	9	1.65	1.08	9	0.37	0.48	9	1.81	0.00
10	1.60	----	10	1.74	0.74	10	0.33	0.19	10	1.21	0.00
11	1.90	----	11	1.33	0.38	11	0.27	0.36	11	1.00	0.00
12	2.22	----	12	1.39	0.51	12	0.54	0.13	12	1.24	0.00
13	2.22	----				13	0.21	0.10	13	1.32	0.36
14	2.21	----				14	0.33	0.10	14	1.71	0.20
15	1.63	----				15	0.29	0.16	15	1.45	0.26
						16	0.31	0.20	16	1.76	0.23
						17	0.34	0.15	17	1.70	0.65
						18	0.22	0.30	18	1.87	0.80
						19	0.46	0.21	19	1.75	0.56
						20	1.39	0.85	20	1.21	0.51
						21	1.65	1.25	21	1.22	0.97
						22	2.06	1.41	22	1.09	0.70
						23	1.50	0.45	23	1.24	0.34

TUIRC (49)		
1	1.40	0.00
2	1.85	0.13
3	1.92	0.00
4	1.60	0.00
5	1.63	0.17
6	1.82	0.00
7	1.93	0.18
8	1.99	0.27
9	2.02	0.85
10	1.60	1.23
11	1.96	0.65
12	2.63	0.92
13	2.35	2.02
14	2.60	0.72
15	2.55	1.28
16	2.47	1.39

GHUIRM (5)		
1	0.56	0.00
2	0.43	0.00
3	0.17	0.58
4	0.80	0.85
5	2.33	1.11
6	1.36	0.95
7	2.40	1.05
8	1.55	0.54
9	1.50	1.10
10	1.74	0.20

SNEACHDA		
1	0.84	0.00
2	0.57	0.00
3	0.92	0.00
4	0.95	0.14
5	0.43	0.59
6	0.64	0.00
7	0.56	0.00
8	0.78	0.00
9	0.70	0.25
10	0.63	0.35
11	0.68	0.13
12	0.58	1.04
13	0.67	0.19
14	0.81	0.43
15	0.69	0.51

FIONN (38)		
1	0.36	0.00
2	1.14	0.00
3	0.81	0.00
4	1.06	0.00
5	1.40	0.00
6	1.80	0.03
7	1.80	0.00
8	1.34	0.27
9	1.31	0.00
10	2.19	0.25
11	1.37	0.17
12	1.74	0.00
13	1.66	0.00
14	1.83	0.57
15	1.63	0.55
16	1.71	0.51
17	1.40	0.35
18	1.70	0.56
19	1.49	0.33
20	1.78	0.44
21	1.79	0.19

FHEARNAGAN (3)		
1	0.60	0.00
2	0.58	0.23
3	0.63	0.00
4	0.75	0.30
5	0.83	0.28
6	0.88	0.57
7	1.00	0.28
8	0.97	0.36
9	0.75	0.12
10	0.74	0.68
11	0.75	1.00
12	1.07	1.47
13	----	----
14	1.05	0.41
15	1.09	0.48
16	1.17	1.49

LURCHERS (13)		
1	0.65	0.00
2	0.73	0.03
3	1.73	0.07
4	1.59	0.79
5	1.39	0.82
6	1.69	0.88
7	1.76	0.88
8	1.55	1.13
9	1.81	1.03
10	1.89	1.06
11	1.76	1.05
12	1.55	1.02
13	1.19	1.24
14	0.64	0.56
15	1.73	0.84
16	1.39	1.18
17	1.55	1.06
18	1.73	1.12

APPENDIX 9: SCORES ON THE PRINCIPAL COMPONENTS.

See Chapter Six for further details (section 6.2). The data used in the principal components analysis are listed in Appendix 7. The numbers in the first column refer to those of the sites listed in Appendix 1. There were eleven components.

	1	2	3	4	5	6	7	8	9
1	1.773	0.277	-0.320	-0.390	-0.862	0.443	-0.404	-0.280	-0.538
2	0.584	0.497	0.164	-1.591	-0.180	2.142	0.402	0.145	0.282
3	1.297	0.610	0.559	-1.605	1.766	0.150	0.595	-0.300	-1.056
4	2.000	-1.149	-0.197	-0.613	0.472	-0.901	1.266	-0.463	-0.246
5	1.213	-0.553	-1.294	-0.617	0.008	0.203	1.881	-0.325	0.036
6	2.046	0.936	-0.774	-0.198	1.314	1.255	-1.333	-1.416	1.250
7	2.811	-0.915	-2.780	-0.283	-0.118	-0.539	0.626	-0.218	1.220
8	0.210	2.348	0.368	-3.912	-0.859	0.751	-0.718	-0.111	0.628
9	-2.363	-1.431	0.211	-2.334	0.011	-1.571	0.253	-0.236	0.297
10	-3.706	-1.048	-0.456	-0.271	0.323	0.697	0.882	-1.022	-0.553
11	1.677	-0.878	-0.482	0.758	0.950	-0.352	-2.287	0.268	0.041
12	-0.890	-0.285	-1.383	0.209	1.357	0.091	0.860	0.687	-0.069
13	1.523	-0.349	-1.481	1.021	0.248	-0.903	-0.785	0.256	0.231
14	-1.312	0.654	-2.135	1.081	1.231	-0.285	-0.614	0.490	0.130
15	-0.334	-1.681	-1.514	-0.120	1.635	0.418	-0.848	0.229	0.563
16	1.029	-0.568	-0.901	-0.791	3.116	-1.092	0.731	-0.220	-0.096
17	1.124	2.524	-0.859	0.322	-0.574	-0.424	-0.168	0.252	0.598
18	-0.595	0.090	-0.650	-0.383	-0.768	0.540	-1.132	-1.211	-0.292
19	-2.663	0.256	-1.884	-0.309	0.124	-0.398	-1.832	-0.389	-0.543
20	-2.135	0.780	-0.738	0.047	-0.108	-0.132	-0.211	0.837	0.404
21	-2.457	0.642	0.417	-1.098	0.291	0.276	-0.807	0.367	-0.412
22	0.896	3.176	2.372	-0.132	0.679	-0.772	-0.081	-0.107	-0.033
23	1.247	3.455	0.615	-0.741	-1.376	-1.537	-0.003	0.027	0.835
24	-2.726	0.302	-0.748	-0.077	-1.184	-0.448	-0.138	-1.119	-0.433
25	-2.769	-0.501	-0.008	-1.121	-1.339	-2.023	0.595	0.155	0.637
26	-2.968	-1.015	0.622	1.827	-0.504	0.252	0.046	-0.410	0.326
27	0.760	1.353	-0.841	0.354	-0.158	0.568	-0.928	-0.738	0.343
28	0.743	0.885	1.452	1.279	-0.608	-0.332	-1.103	-0.493	-0.213
29	-2.173	1.492	-0.429	2.040	0.133	-0.621	0.819	-0.658	-0.298
30	-1.321	0.799	-0.319	1.582	-0.461	-0.933	1.132	-1.097	0.162
31	3.305	0.671	-0.571	0.476	0.228	1.275	1.369	-0.555	-0.796
32	1.101	-1.784	4.218	0.119	1.369	-0.025	-0.380	-1.466	0.743
33	-0.536	-1.744	1.473	1.869	0.368	-0.703	0.435	-0.073	1.773
34	1.105	0.227	1.707	1.378	0.370	-0.994	0.027	0.966	0.008
35	1.639	1.145	0.919	1.042	0.302	-1.347	-0.434	1.948	-0.575
36	0.554	0.579	1.504	-0.953	0.132	-0.230	0.819	1.300	-0.707
37	-1.205	1.073	-0.455	-0.462	0.427	-0.617	0.093	0.096	-0.615
38	0.543	-0.083	0.686	0.172	-0.816	-0.722	0.265	-0.153	-0.830
39	1.264	-1.373	-0.265	0.542	-2.289	0.451	-0.908	0.262	-0.256
40	1.784	-0.215	0.514	1.562	-1.179	1.242	0.834	-0.738	0.346
41	1.798	-0.418	-0.500	0.870	-0.926	0.351	0.385	-0.011	-0.596
42	-0.589	-0.562	0.406	0.909	0.406	0.254	-0.639	-0.418	-1.549
43	0.446	-2.006	1.019	-0.691	0.176	0.303	-0.603	2.012	0.097
44	0.109	-0.886	-0.180	0.289	-0.830	1.248	-0.402	1.107	-0.108
45	-0.140	-0.450	2.079	0.234	0.716	1.000	-0.214	-0.304	-0.412
46	1.042	-3.292	1.362	-1.967	-1.206	-1.183	-0.322	-1.152	-0.415

	1	2	3	4	5	6	7	8	9
47	1.398	-1.516	-0.616	0.074	-1.646	-0.979	0.036	0.483	0.017
48	-1.478	-0.169	0.261	-0.077	-1.053	1.548	1.322	1.493	0.750
49	-0.575	0.654	0.002	-0.050	0.255	0.951	1.520	-0.005	0.499
50	0.397	0.914	-0.513	0.685	-0.278	0.153	0.630	0.046	-0.869
51	-3.219	0.622	2.445	0.337	0.699	1.305	-0.108	0.628	0.466
52	-1.528	0.717	-0.685	0.119	0.869	0.822	-0.003	0.241	0.053
53	0.382	-1.608	-1.200	-0.643	0.485	-0.047	-0.025	1.076	-0.098
54	-0.117	-1.202	-0.193	0.230	-1.140	1.440	-0.394	0.320	-0.125

	10	11		10	11
1	-0.330	-1.014	28	0.263	0.291
2	-0.179	0.250	29	-0.283	0.178
3	0.584	0.164	30	-0.042	0.002
4	0.557	0.256	31	0.523	1.190
5	0.266	0.641	32	-0.221	0.249
6	0.582	-0.188	33	0.125	-0.058
7	0.436	0.160	34	0.393	0.479
8	0.422	0.003	35	0.545	0.279
9	0.938	-0.494	36	-0.888	0.343
10	0.536	-0.628	37	-0.098	-0.223
11	-0.158	0.436	38	0.146	-0.114
12	-0.363	0.036	39	-0.615	0.244
13	-0.184	0.184	40	-0.340	-0.969
14	-0.603	-0.236	41	0.091	-0.372
15	-0.395	0.743	42	1.016	-0.131
16	-1.284	-0.552	43	0.474	-0.853
17	-0.420	-0.597	44	-0.059	-0.142
18	-1.310	0.284	45	0.087	-0.340
19	0.412	0.230	46	-0.916	0.222
20	0.083	0.550	47	0.681	-0.368
21	0.068	0.714	48	-0.055	0.625
22	-0.261	-0.363	49	-0.161	-0.010
23	-0.182	0.037	50	-0.468	-0.457
24	-0.299	0.539	51	-0.328	0.080
25	-0.061	0.028	52	0.249	-0.908
26	0.559	0.097	53	-0.112	-0.414
27	0.958	-0.094	54	-0.377	-0.010