VEGETATION-SNOW RELATIONSHIPS IN LABRADOR

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ABSTRACT

A study of vegetation-snowcover relationships in the Elizabeth Lake basin, Labrador, involved the calculation, allocation and collection of a large random sample of depth, density and water equivalent of snowcover. Procedures involved and methods of analysis, including analysis of the data using computer mapping techniques, are described. Snowcover developed on Tundra and Lake and Woodland areas proved to be distinct but differentiation between Open Lichen Woodland and Close Lichen Woodland was less clear. Characteristics of snowcover in the basin and for each cover type, for late February 1979, are discussed in detail.

INTRODUCTION

There is a modest body of literature devoted to areal differentiation of snowcover at the mesoscale (c. 10^2-10^3 m linear scale, Gray,1978). The studies concerned (e.g., Adams,1976; Kuz'min,1960; Meiman,1970; Steppuhn,1976;and,Steppuhn and Dyck 1974) attempt to identify distinctive snowcover characteristics for distinctive "landscape units". The landscape units are identified in terms of such variables as slope, aspect, altitude and surface roughness including vegetation. The most common practical objective of such work is the determination of basin snowcover for the purposes of spring runoff prediction but explanations of and generalization about patterns of permafrost (e.g., Granberg,1978) and various recreational and biological patterns have also been sought in this way.

Relationships between landscape units defined in terms of agricultural and natural vegetational cover are particularly useful as the extent and nature (species composition, spacing, completeness of cover, height etc.) of vegetation can be established quickly and accurately for large areas. These allow rapid and meaningful extrapolation from test vegetation-snowcover sites to the region concerned.

The study, for which this is a preliminary report, was undertaken in the centre of the Labrador-Ungava Peninsula, close to the Hudson Bay-Atlantic divide (Fig. 1). The study area is in the Churchill Falls drainage area but is within a kilometre of the Churchill/Arctic divide in an area which is being mined by the Iron Ore Company of Canada (IOCC). Results therefore are of interest for both the Baie James and Churchill Falls hydroelectric operations and for engineers working in the Schefferville mines.

In terms of snowfall, this is an area which receives approximately 36 cm water equivalent per winter, with snow on the ground from September to June and with a more or less complete snowcover from October to May (Tout,1964). In terms of snowcover, the snowfall of a typical winter produces a peak snow depth of 120 cm in sheltered bush locations and 50 cm at more open, lowland sites (Adams et al.,1966, Fig. 1).

The vegetation of the region is within the broad transitional Open Boreal Woodland zone which characterizes much of the Labrador-Ungava peninsula (Hare,1950). It ranges from Tundra on ridgetops, which rise approximately 400 m above the valley floors, through Open Lichen Woodland (trees 7-12 m apart) to Close Lichen Woodland (trees 2-6 m apart). Lichen Woodland is a vegetation type which is characterized by black and white spruce trees (with a typical mature height of 10 m and diameter of 20 cm) with a distinctive ground cover of

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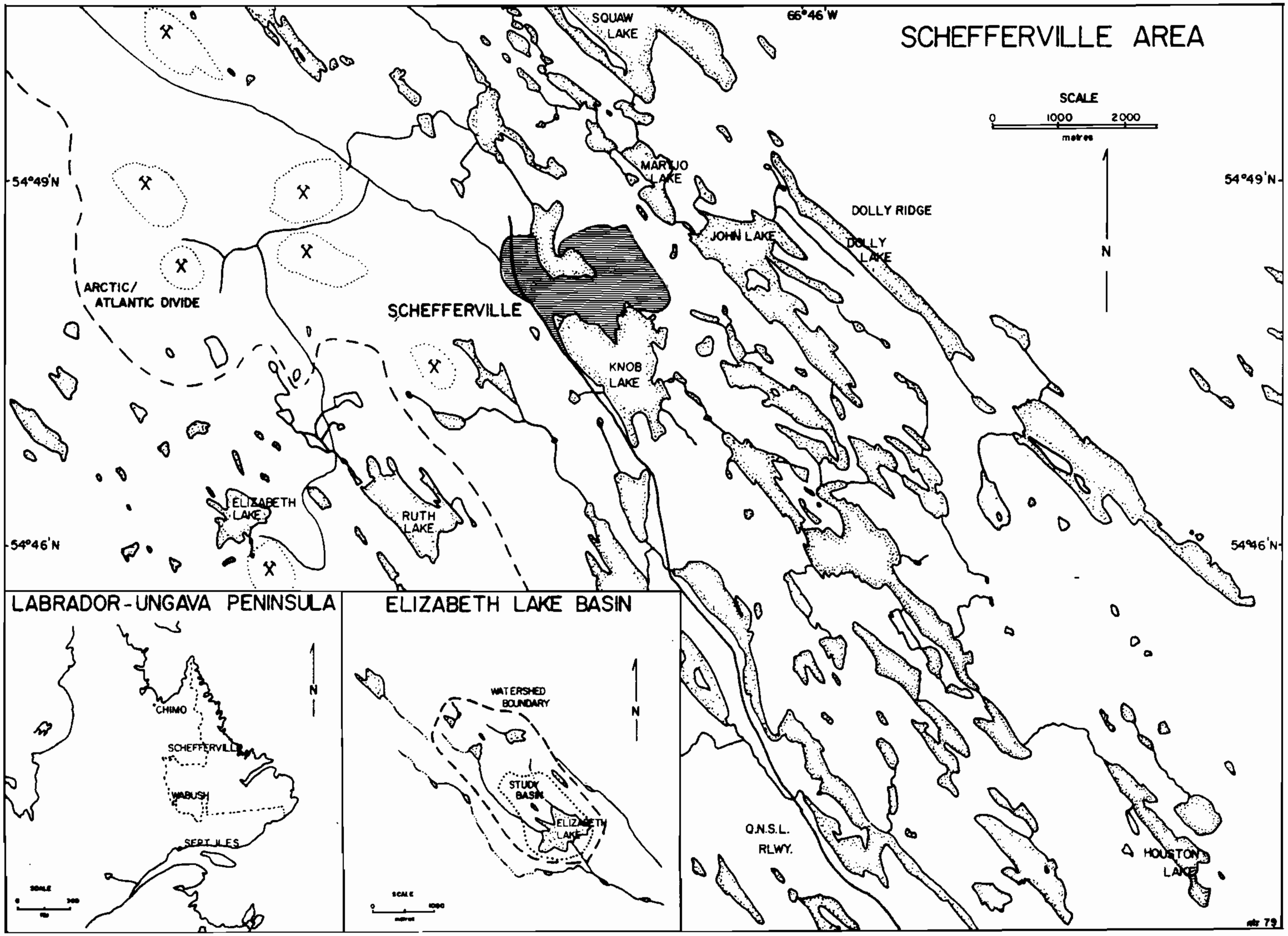

Figure 1. Location of Elizabeth Lake.

lichens (predominantly *Cladonia* spp) and small shrubs (Fraser,1956; Hustich,1954). Forest, in the strict sense, is very restricted indeed in the study area. In general, the height of trees decreases and their sparseness increases from the south and east towards the north and west in the peninsula as a whole.

Geologically the study area is within the Labrador Trough of the Canadian Shield which finds topographic expression in a series of NW-SE ridges and valleys. A large proportion of the valley floor is occupied by lakes which form more than 20% of the surface area of the region. These lakes form a distinctive 'landscape unit' in themselves as they are for the Canadian Shield as a whole.

Studies of areal differentiation of snowcover, in terms of vegetation and other surface characteristics, have been carried out in the area before (e.g., Adams et al.,1966; Adams and Findlay,1966; Adams and Rogerson,1968; Findlay,1966; Granberg,1978). In each of these studies, relatively large samples were used in an effort to avoid the limitations of many studies of this type which, because of the difficulties of snow surveying in the field, suffer from under-sampling. Adams and Rogerson (1968) develop the point that the lakes form a particularly important and distinctive landscape unit for snowcover development in this region. A discussion of the special characteristics of lake snowcover can be seen in Adams and Prowse (1978).

Objectives

The principal purpose of the study was the identification of vegetation-related patterns in the snowcover of central Labrador-Ungava and establishment of relations between land snowcover patterns and patterns on lakes in the area. An important methodological objective was the development of an effective, practical, procedure for identifying snowcover units. Because of this last point, considerable emphasis was placed on the design of the sample, on the program of data collection in the field and on procedures for processing the large amounts of data generated by the field program.

PROJECT DESIGN AND METHODS

Study Area

The area which was chosen for the study was the basin which contains Elizabeth Lake, Labrador, 8 km south and west of Schefferville (Fig. 1). This basin is not the entire catchment of the lake system as two deep glacial drainage channels greatly extend the watershed. However the NNW/SSE aligned topographic basin was selected for study because it contains a sizeable lake and a good cross section of the vegetation types of the area, because it encompassed a useful altitudinal range (276 m) (Figs. 2 and 3) and because, as an approximately oval basin it provides a relatively self contained unit which has a more or less compensating range of aspect and slope with respect to the prevailing NW wind direction.

Basic information on the basin, including relative and actual areas occupied by the main 'landscape units' is presented in Table 1. The basin was divided into four easily recognizable 'landscape units' which appeared likely, from the literature (e.g., Adams et al.,1966; Findlay,1966; Granberg,1978), to develop distinctive snowcovers. These were the Lake (L) itself, and three vegetation types, Tundra (T), Open Lichen Woodland (OLW) and Close Lichen Woodland (CLW). These units were identified from aerial photographs and were adjusted by ground surveys. Vegetation and relief were plotted at a scale of 1:4,800 to form the basic working map for both fieldwork and analysis. The landscape units are shown in Figure 3.

Calculation of Sample Size

The main feature of the field program was a very large sample of depth, density and water equivalent of the snowcover using Canadian M.S.C. and Mount Rose snow tubes. In addition, a number of stratigraphic profiles were obtained for each landscape unit. The sampling program used was designed to avoid theoretical and practical limitations of similar surveys in the literature.

ELIZABETH LAKE BASIN: TOPOGRAPHY

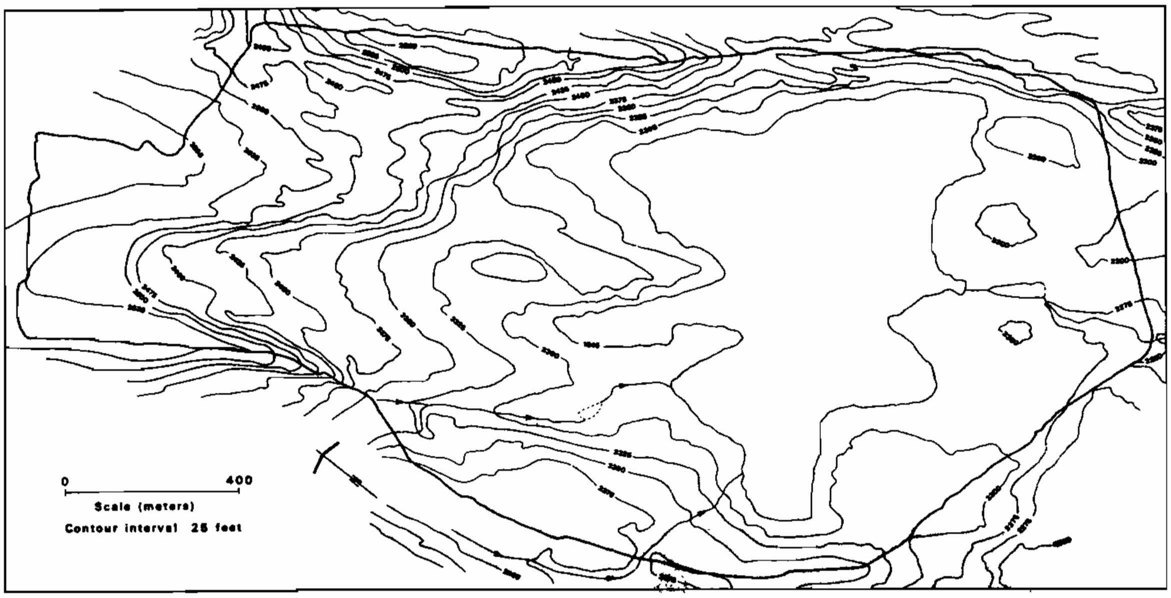

Figure 2.

ELIZABETH LAKE BASIN: LANDSCAPE TYPE

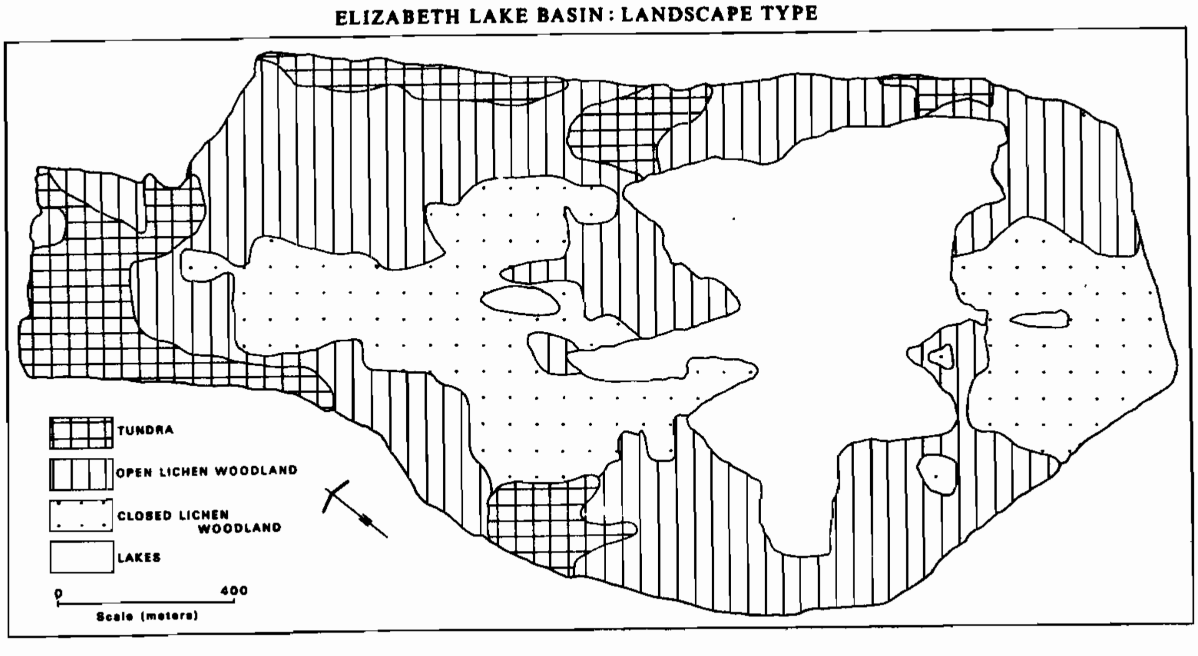

Figure 3.

Sample size was calculated using the relationship

$$n = \left(\frac{Z\sigma}{E}\right)^2 \qquad \text{(Hammond and McCullough,1974)} \qquad (1)$$

where n is the desired sample size, σ is a standard deviation and E is the maximum error of estimate of the mean. The Z score in large samples at the 95% confidence level is 1.96.

In this study it was possible to approach calculation of sample size in various ways. Given a standard deviation, it would, for example, have been possible to calculate a sample size for each snowcover property (depth, density and water equivalent) for the basin as a whole. Or, alternatively, given standard deviations, it would have been possible to calculate sample sizes for each selected landscape unit and for each snowcover property. As the variability (in terms of the standard deviation) of each cover type and of each property might well be different, this last procedure would involve the calculation of 12 (3 properties x 4 landscape units) sample sizes.

With seasonal phenomena, such as a snowcover, estimation of a standard deviation presents a problem in that there is no reason to believe that one year's variability will be replicated in another year. Thus even where suitable records are available there may be no real advantage to using a previous year's standard deviation for calculating sample size except that it establishes an order of magnitude. One answer to this problem is the design of a very large sample, one which is larger than the expected desirable sample size, before going into the field and then calculating final sample size in terms of, say, measurements at the first thirty randomly selected points.

The procedure used in the study was as follows:-

1. The maximum error of estimate of the mean was set at ±2.54 cm (1") of snow depth as this was a practicable measuring error with the survey equipment which was non metric.

2. A standard deviation for depth of snow on lakes was extracted from the literature (Adams and Brunger,1975). Depth was the only property for which sufficiently detailed information existed for all four landscape units. The Lake case was used because it appeared from the literature to develop the snowcover which was relatively the most variable of the four landscape types under study. Thus it was expected that the standard deviation would be a relatively high one in terms of all three properties and all four vegetation types thus producing an n value which, if anything, would be too high.

3. The confidence level was set at 95%.

4. The appropriate values were inserted in Equation 1 and a sample size of 131 was derived for the lake. Sample sizes were then calculated for each of the other landscape units in proportion to their areas giving a total calculated sample size for the basin of 614 points.

In snow survey work, large samples present an important practical problem in that a survey must be completed in a relatively short time so that significant changes in the snowpack do not occur during the period of measurement. In this case, the surveys were undertaken in February which has a mean temperature in the Schefferville area of less than -20°C so that metamorphic changes in the cover are slow. However snowfall is frequent. The sample size, obtained by using a standard deviation of lake snow depth from previous years, seemed practicable for a group of 22 experienced persons working for from 3-5 days in a relatively small basin*. The distribution of points used is shown in Figure 4.

Allocation and Location of Sample Points

The sample points were allocated on a 1:48,000 scale map of the basin using a

* As a fail-safe procedure, sampling, in the field should ideally be undertaken as a series of smaller, but complete, random samples. This insures against changes in weather conditions etc.

1 cm^2 grid overlay and random number tables. One point per grid square provided the required density and allocation within the square was random. Adjustment of the vegetation boundaries determined from aerial photographs, as a result of field observations, resulted in the slight variations in density of points shown in Table 1. The lowest density was for CLW (10.5 points/ha), the Lake, which was the subject of special study, had a density of 11.8/ha.

The location of randomly distributed sites in the field is a time consuming business. It is for this reason that most snow surveys rely on straight line or grid snow courses. In this case the sites were located by turning right angles and chaining from the control lines of stakes (Fig. 4) which were established in the fall. At the beginning of the survey, the two control lines were trampled with snow shoes to form straight, packed, paths. Then two further control lines, at right angles to the staked lines were packed. Members of the group, working in pairs, were issued with instruction sheets locating their allocation of stakes in terms of distances and right angles from points on the control lines. Examples are given in the caption of Figure 4. The right angles were turned by means of orienteering compasses--which were quite adequate as protractors for this purpose despite the presence of large quantities of iron ore in the region which affected their efficiency as magnetic compasses.

Samples were individually bagged and were weighted at the field station each evening. Surveyors were encouraged to make notes on sample sites and problems.

In the event, the surveys were completed in 6 days (5 working days), i.e., 21 to 27 February 1979, during which only 5.2 cm of snow (5.2 mm water) fell. Mean daily temperatures ranged from -12.5°C to -30.9°C and there was only one day with blowing snow.

Data obtained were analysed using the SYMAP (Carleton Edition 5.2.3) computer mapping package and standard SPSS (Statistical Programs for the Social Sciences) for statistical calculations. The computer system used was the Xerox Sigma 9 Computer System of Carleton University, Ottawa which is available at Trent University, Peterborough, on a time-sharing basis. The wind roses on the maps represent days of wind during the 1978/79 winter.

Commentary on Sampling Design and Procedures

A certain number of mistakes are inevitable when a group of 22 snow surveyors are working as quickly as possible under extremely severe conditions. As a result of such errors, data obtained for a number of points were eliminated. The distribution of points used for calculations is shown in Table 2.

This represents a slight reduction in the calculated total but provides a very adequate coverage of the basin and its component landscape units.

Using standard deviations obtained in the survey and the appropriate n values, Equation 1 provides the standard errors listed in the left half of Table 3. These values are clearly higher than the 2.54 cm which was used in designing the sample. The reason for this is that standard deviations encountered were higher than expected for each landscape unit (see Table 4). It would appear that standard deviations in Adams et al. (1966) would have given a better indication of those encountered than those in Adams and Brunger (1975). A sample size of over 2,500 would have been required to achieve a standard error of 2.54 cm. Table 3 also gives an indication of the improvement which the large sample did represent as compared with the selection of only thirty sample points for the whole basin and for each landscape unit. It is interesting to note that the lake case, which was assumed to be the most variable in terms of depth, is least affected by the increase in sample size. Standard errors for density and water equivalent using the large sample are shown in Table 4.

The sampling procedure in the field proved quite practicable although packing the control lines took longer than expected because some control stakes were buried and because the control lines selected included some very difficult terrain. It would be better to deliberately select easy routes for the control lines and to mark trees, well above

Table 1

Areal Distribution of Original* Sample Points

Landscape Types	Area (ha)	Relative Area	No. of Sample Points	Relative No. of Points	Density of Sample Points
Basin	50.31	100	614	100.00	12.20
Lake	11.08	21.73	131	21.34	11.82
OLW	20.46	40.11	256	41.69	12.51
CLW	12.08	25.03	127	20.68	10.51
Tundra	6.69	13.13	100	16.28	14.94

* The distribution shown here represents the sample as originally designed, the points used in the analysis are shown in Table 2.

Table 2

Actual Distribution of Sample Points

Landscape Type	Relative Area %	Number of Points	Relative No. of Points %	Density pts/ha
Basin	100.00	526	100.00	10.45
Lake	21.73	129	24.52	11.64
OLW	40.11	216	41.06	10.56
CLW	25.03	107	20.34	8.86
Tundra	13.13	70	13.31	10.46

Table 3

Standard Errors for Depth (cm) Obtained in the Survey

Landscape Type	n	Standard Error	n	Standard Error
Basin	526	5.69	30	26.43
Lake	129	3.62	30	4.79
OLW	216	8.12	30	21.91
CLW	107	7.79	30	14.64
Tundra	70	14.15	30	20.99

Table 4

The Standard Errors for Depth, Water Equivalent and Density for the Basin and Four Landscape Types

	Depth (cm)		W.E. (cm water)		Density (g cm^{-3})	
Landscape Type	σ	S.E.	σ	S.E.	σ	S.E.
Basin	66.67	5.69	19.95	1.70	0.084	0.007
Lake	20.97	3.62	11.43	1.97	0.068	0.012
OLW	60.87	8.12	20.54	2.74	0.079	0.010
CLW	41.11	7.79	14.09	2.67	0.066	0.012
Tundra	60.44	14.15	17.06	3.99	0.092	0.021

The sample was designed on the basis of assumptions about the frequency distribution of snow depth. A standard deviation (σ) of 9.31 cm was used in calculating sample size.

ELIZABETH LAKE BASIN: SAMPLE POINT DISTRIBUTION

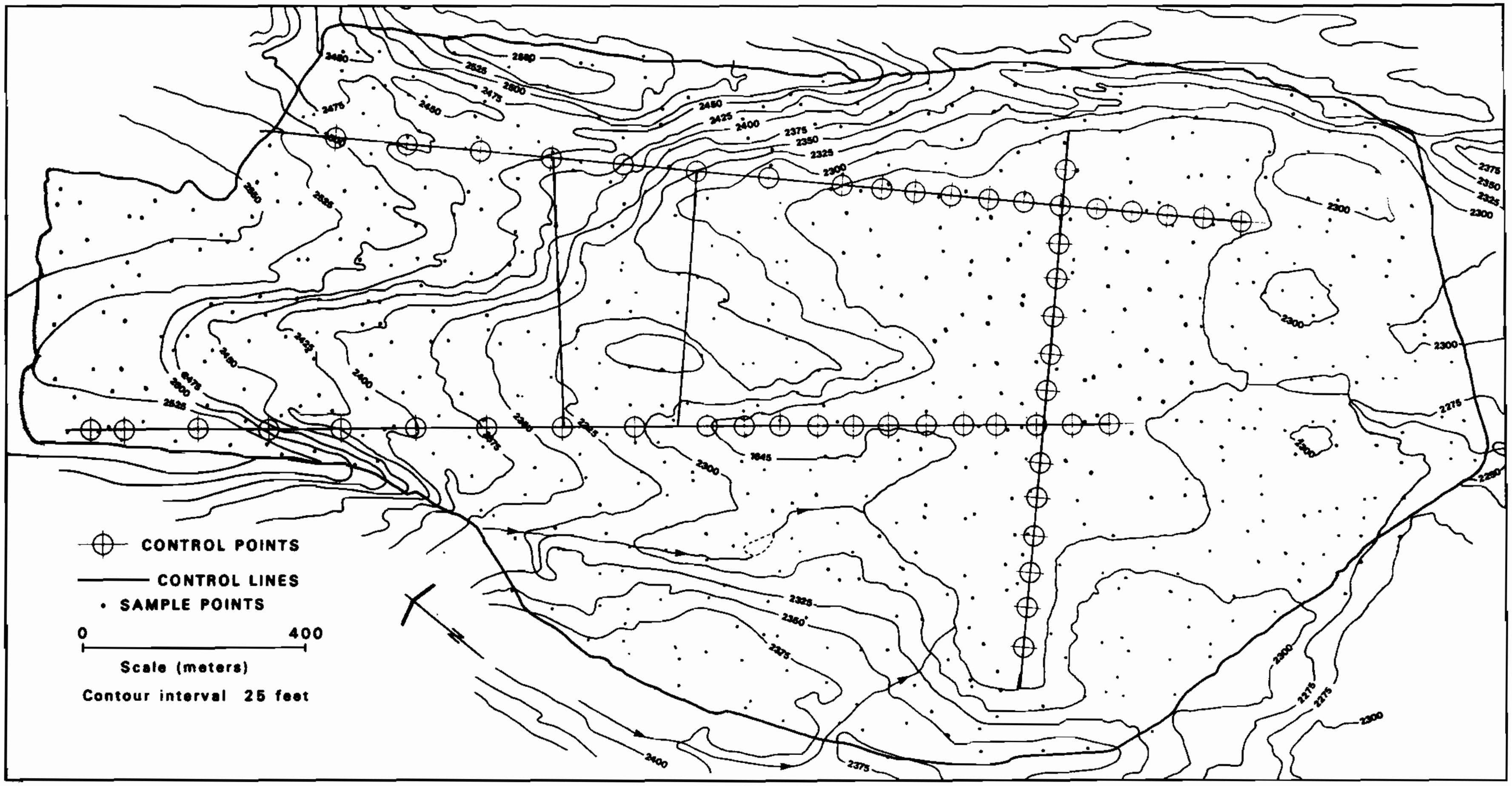

Figure 4. A typical set of instructions for locating sites in the field would be...For sample point #1 - Proceed 60 m north on eastern control line from control point A, turn a right angle to the west 5 m.

ground level, with survey tape to locate them. The fact that the main control lines were high, allowing good visibility over the basin, was, however, an asset. There were some problems with marking plastic bags and transporting large amounts of snow. Wax crayons are much more effective than felt tip markers for writing on plastic in cold weather. Large, pack frame-type rucksacks (supplied by the Canadian Armed Forces) appear to be best for bulky snow samples.

Surveyors were instructed to sample exactly where their chaining led them. In general they did this although there was some tendency for people to avoid sites where it was difficult to handle the snow tubes--as, for example, hard against the trunks of trees or on high angle slopes. This may have some possible effects on snow depths measured (Roulet,1979).

RESULTS

Spatial Patterns

Data collected were processed, displayed and analysed by means of the SYMAP computer package. Seven maps, with associated statistics, were produced for each property measured; depth, water equivalent and density. These maps comprised one isopleth map, to display the spatial distributions in terms of normal interpolation, three trend surface maps and three maps showing residuals from the trend surfaces. First (linear), second (quadratic) and third (cubic) order trend surfaces were fitted. The maps were printed using 12 characters, L1234567890H, in ascending order. Intervals were selected in terms of the range of data although an attempt was made to maintain equality between the order of magnitude of intervals and to keep the mean as the mid point of the intervals on the depth and water equivalent maps.

When the maps were printed, they were coloured and annotated by hand so that patterns could be discerned more easily. After study of the maps in this form, it was decided that three maps, the isopleth map, the third order trend surface and the first order trend residuals map were the most useful for discussion purposes. The first of these is important because it shows the 'actual distribution', the cubic surface produced the highest percentage explanation of the three trend maps while still providing an intelligible distribution and the residuals from the first order trend provided most detail in terms of areas which were relatively anomalous and isolated local patterns. Table 5 contains correlation coefficients, coefficients of determination and percentage variation explained by the cubic surfaces. These maps were originally printed at a size of 30 cm by 55 cm, representing a scale of 1:4,800.

Figures 5-13 were produced from the original printouts, Figure 13 illustrates the original form of the maps.

Figures 5-7 are representative of the variability of snow depth in the Elizabeth Lake basin. The 'landscape units' under discussion are shown in Figure 3. The influence of the Lake (L) (low snow depth) is immediately apparent as is the effect of the main areas of woodland (above average depth). Quite large sections of the rim of the basin also exhibit low snow depths; there are windswept locations where Tundra (T) is present. Locations where the rim has deep snow are characterized by woodland vegetation except in the south east. Greater depths on the southeast portion of the rim, at the downwind end of the basin are a result of deposition on the slope.

The residuals from the linear trend surface (Fig. 6) fitted to the distribution shown in Figure 5 bring out the Lake even more precisely as a zone in which depths were over-predicted. At the southern end of the basin, the Close Lichen Woodland (CLW) remains distinct but the zone of higher snow depths north of the lake is broken up somewhat. The pattern around the basin rim remains essentially the same with a predominance of over-predicted (i.e., low) depths.

The third order trend surface map for snow depth (Fig. 7) exhibits a surface the topography of which includes a round hill in the north centre of the basin and a partial oval depression in the south centre. The hill seems to be a combination of the effects of

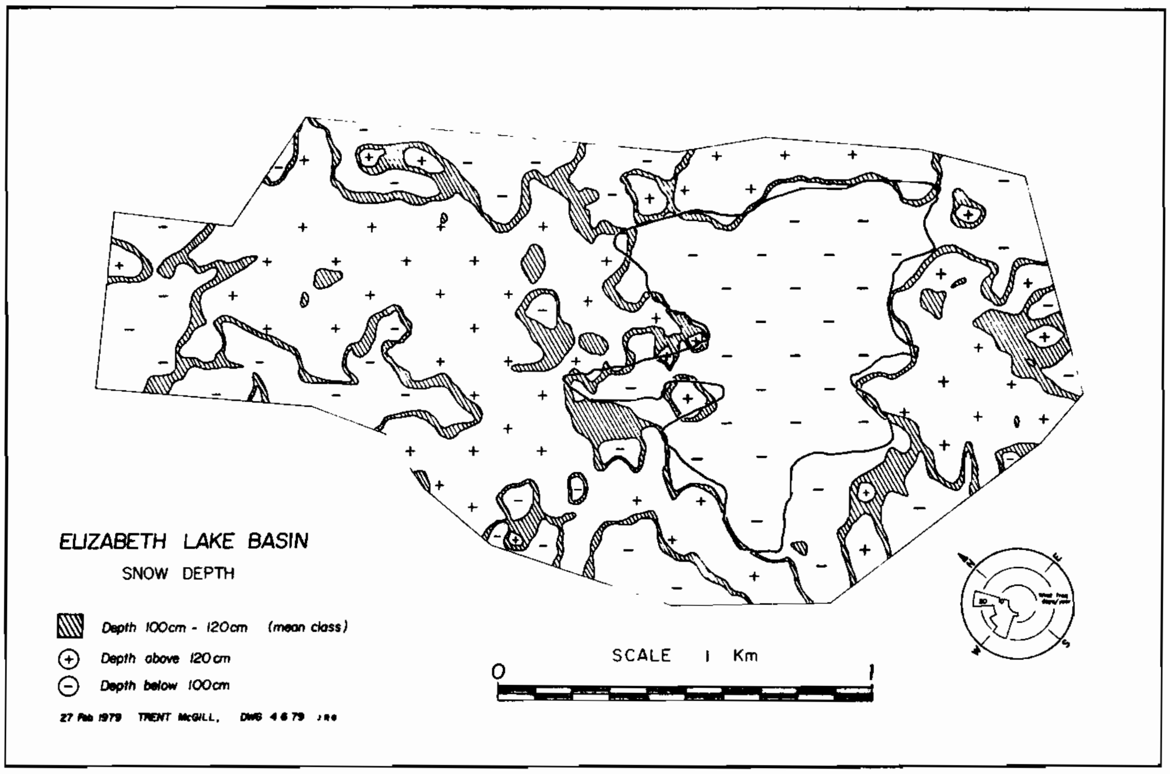

Figure 5. Normal interpolations for snow depths.

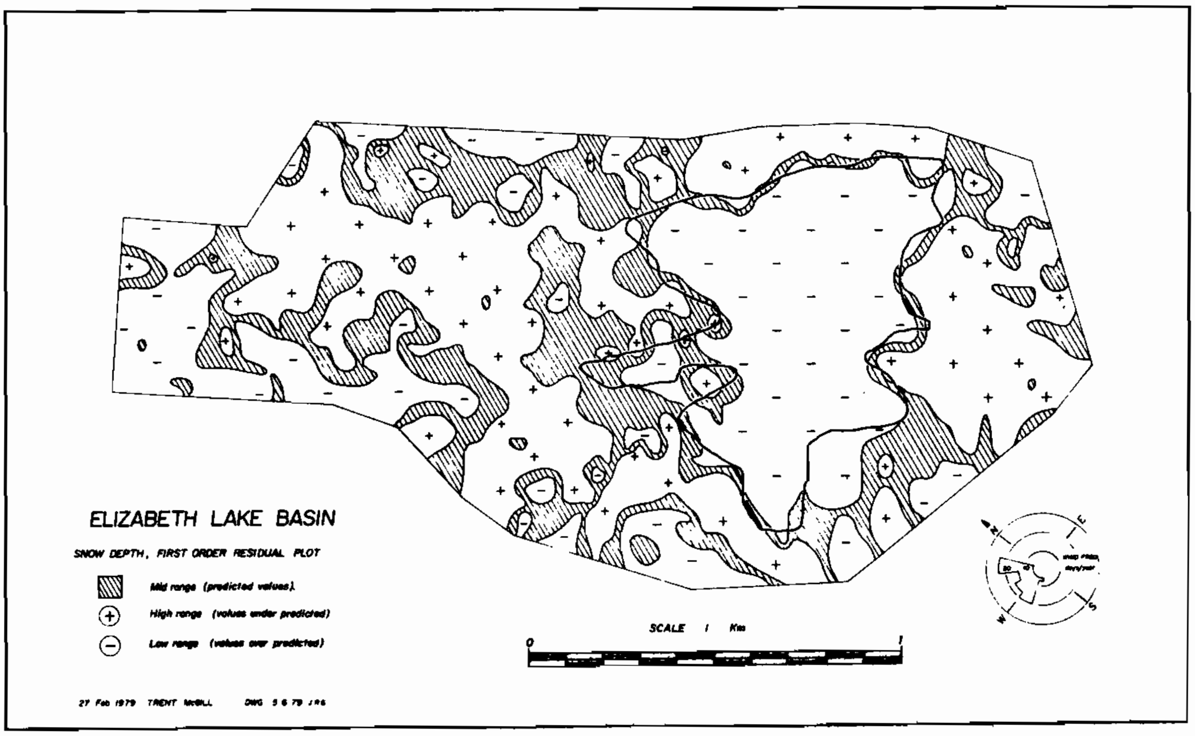

Figure 6. Residuals from first order trend surface, snow depths.

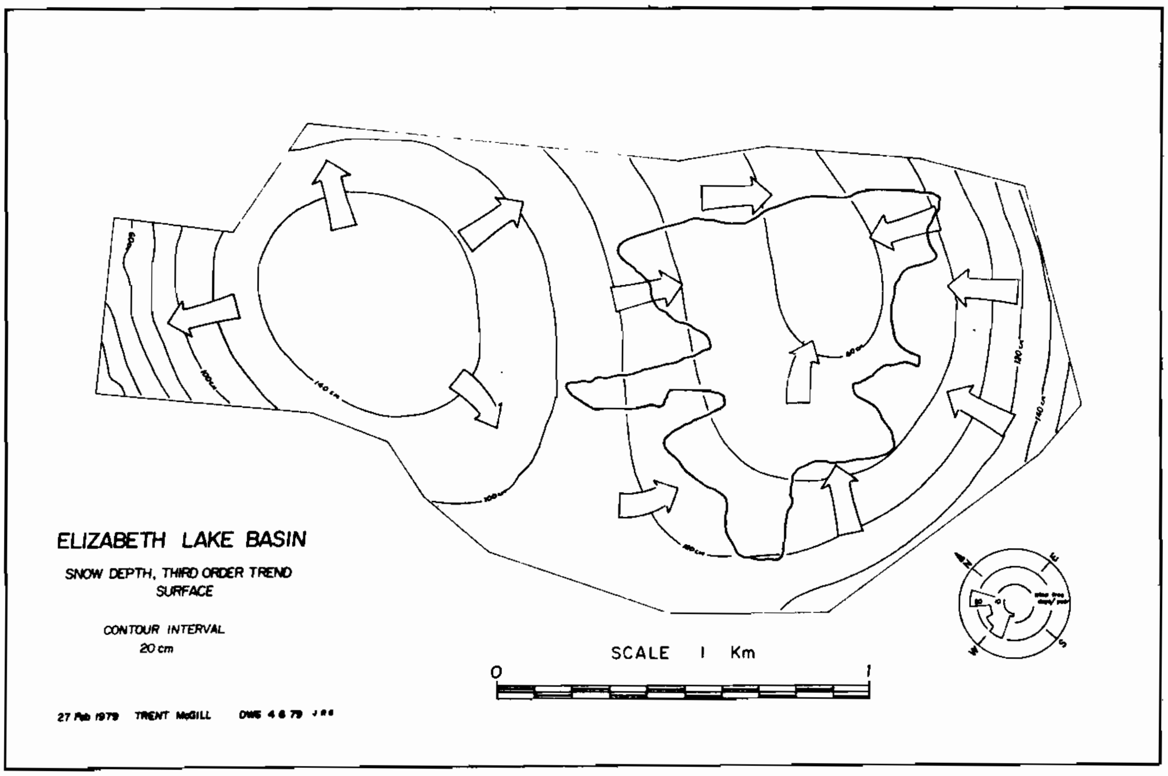

Figure 7. Third order trend surface, snow depths.

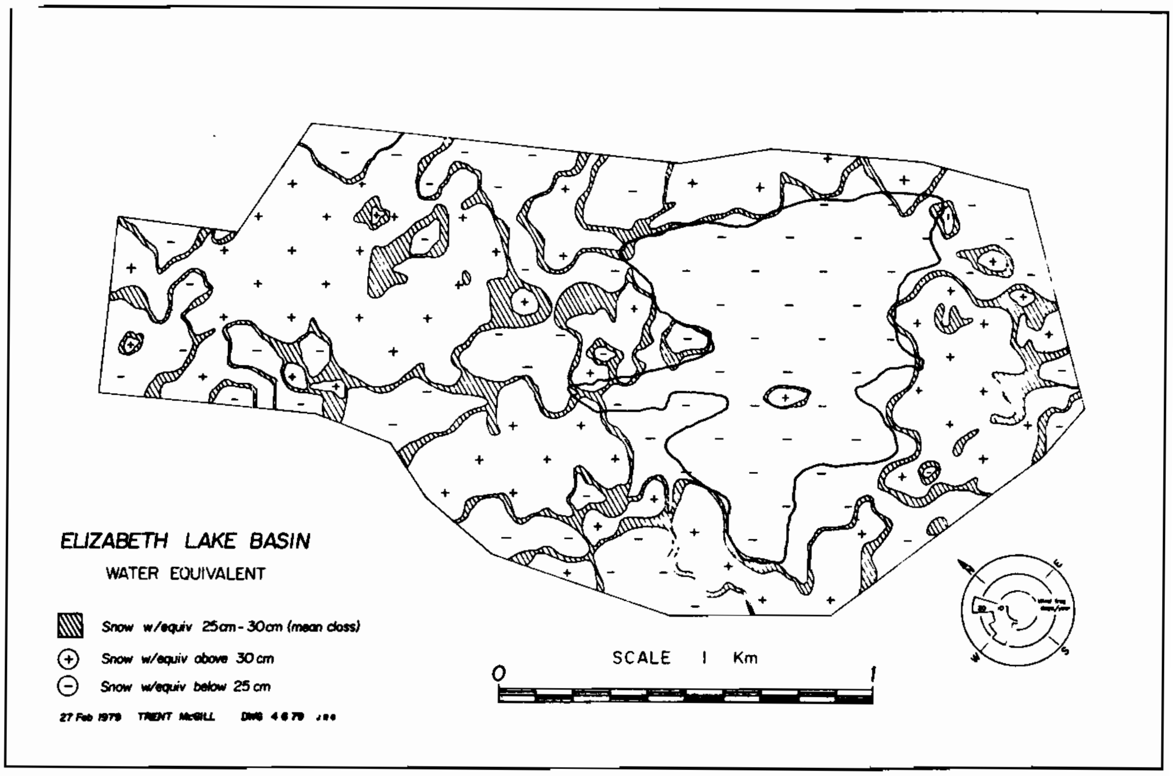

Figure 8. Normal interpolation for water equivalents.

vegetation (CLW) and of deposition in the bottom of the basin as a result of the prevailing WNW-NW wind. The hill has a particularly steep gradient on its upwind side where there is a rapid transition from exposed Tundra to CLW. The depression, as might be expected from Figure 5, is firmly based on the lake with steepest gradients, leading up into the CLW which occupies the southern portion of the Elizabeth Lake basin. This area of vegetation, hard by the lake and downwind from it, is the best example of CLW in the area. This is a recurring pattern in the Labrador Trough. It is interesting that the isopleths which demarcate the depression are open towards the east--if this were a normal topographic map, they might be expected to close, forming an enclosed oval hollow, to the right of the diagram. This was one of the rim areas with relatively deep snow mentioned above.

The isopleth map of water equivalent (Fig. 8) shows a pattern which is broadly similar to that of snow depth, suggesting that the one is a reasonable indicator of the other. The central woodland areas appear more broken up. One reason for this is the presence of a small lake to the north of Elizabeth Lake (Fig. 3). This lake and its effects are more apparent in the distribution of water equivalent than in the distribution of depth. Elizabeth Lake itself is clearly in evidence as an area of low water equivalent but is rather less precisely demarcated here than in Figure 5. It is interesting that a small area of high water equivalent occurs near the middle of the Lake.

In Figure 9, the pattern of residuals again brings out the Lake outline clearly, but, except for the CLW zone south of the Lake, it further breaks up the woodland zones. This last re-affirms the presence of the small lake, which is precisely picked out as an area ofover-prediction (low snow). Here again, the interplay of depth and density must have effect. The CLW area south of the Lake persists as a solid area of high water equivalent (under-prediction). This is a hint of an upwind (WNW)-downwind pattern in the basin.

The various maps discussed so far are representations of the spatial distribution of samples which have the frequency distributions shown in Figures 14 and 15. These are discussed in greater detail below but the dominance of below average values in Figures 5 and 8 and of over predicted values in Figures 6 and 9 reflect the dominance of low values in the frequency histograms. The importance of the lake area in the positive skewness of the basin frequencies is apparent by inspection of its histograms.

The patterns of density (Figs. 11, 12, 13) are quite different. The predominance of average values in Figure 11 reflects the more normal distribution of density frequencies which is displayed in Figure 16. The lake no longer appears as a reasonably distinct outline although its general area is occupied by average density values. The Tundra area of the windswept northern end of the basin shows up clearly as a zone of high density and the main CLW areas tend to exhibit mean to low densities. There is some suggestion of an edge effect in the woodland areas--lower densities towards the centre of stands. There is also some suggestion of an area of higher density at the downwind end of the Lake.

The first order residuals (Fig. 12) show few marked deviations from the trend surface. This is a result of the dominance of the mean in the frequency distribution for density.

The cubic trend surface for density (Fig. 13) shows a depression in the west centre area of the basin, in the lee of the western rim with a rise outwards from this in most directions towards the rims and the lake. This does suggest a basin-vegetation effect--a general increase in density from low (woodland and sheltered) to high (tundra and exposed) areas, complicated by the presence of the lake (a wind swept area) in the bottom of the basin. The other area of low density, at the extreme south end of the basin is the lee side of the CLW zone which has been mentioned previously. Densities increase upwind through it, out onto the lake. This is an example of a zone which is characterized by high water equivalent <u>despite</u> low densities as a result of very high snow depths.

Areal Differentiation

Summary results of the Elizabeth Lake snow survey are presented in Table 6. There was a mean depth of 100.9 cm of snow in the basin, with a water equivalent of

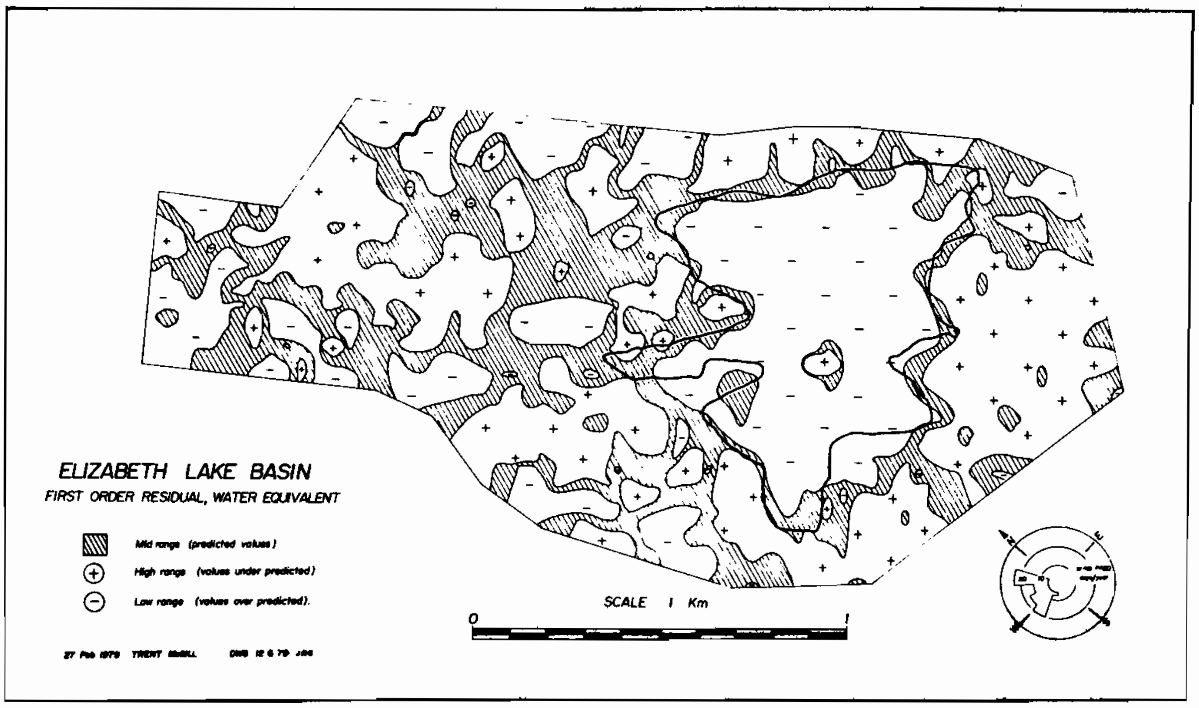

Figure 9. Residuals from first order trend surface, water equivalents.

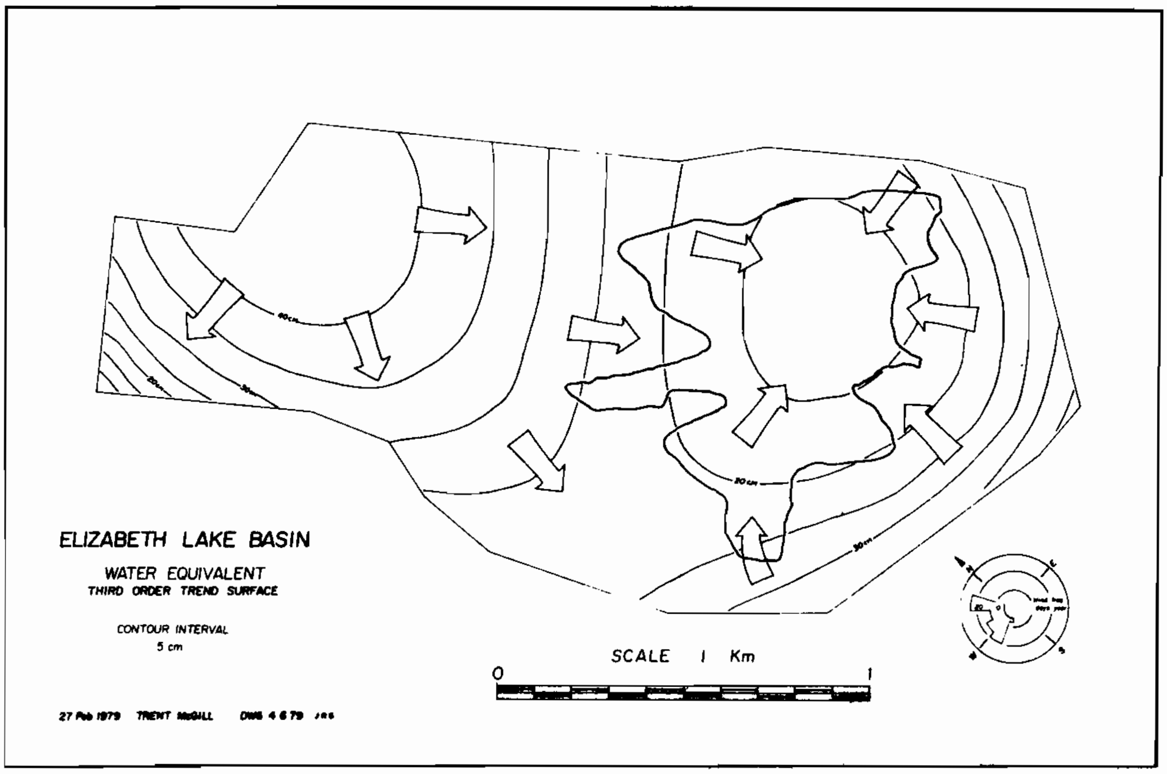

Figure 10. Third order trend surface, water equivalents.

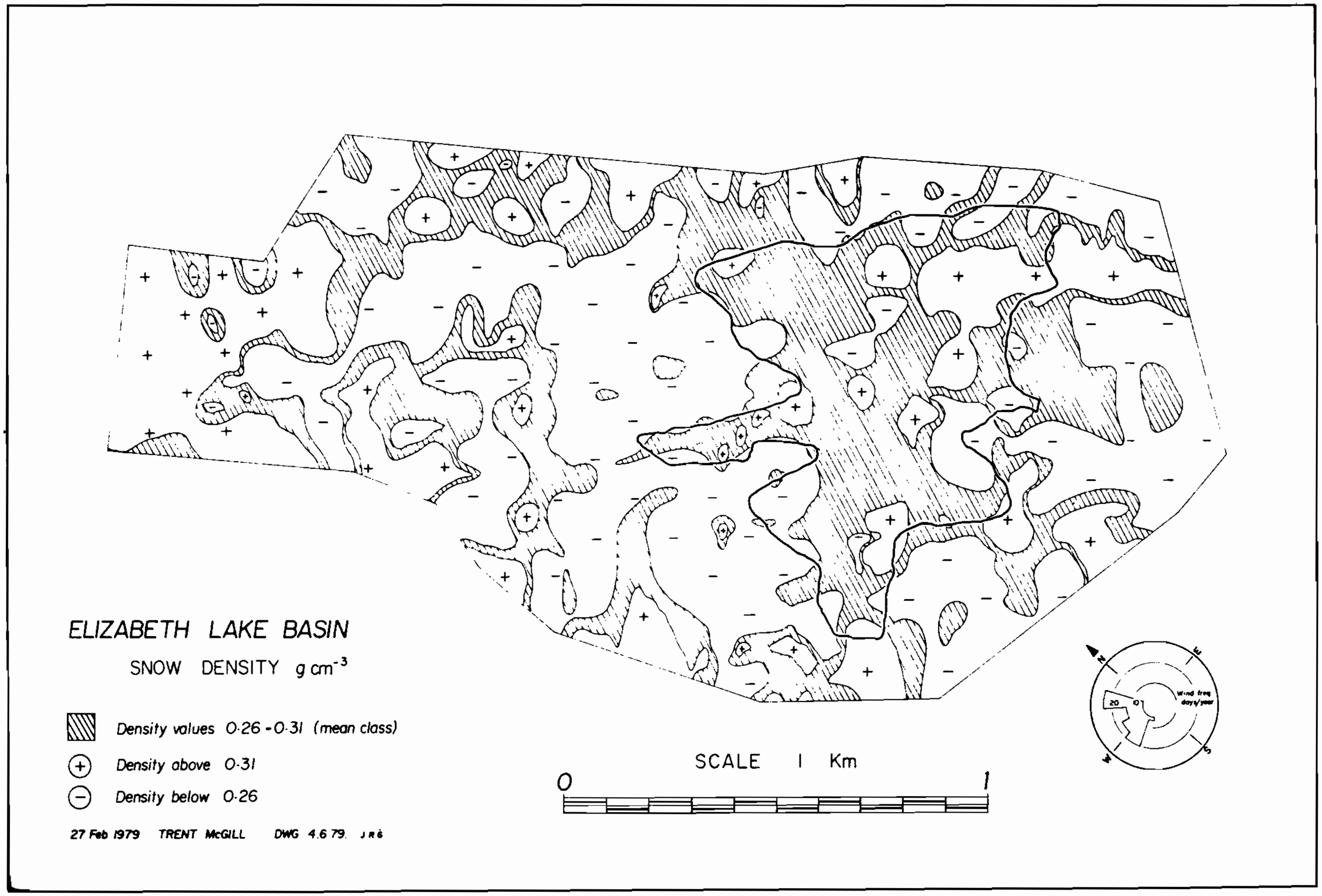

Figure 11. Normal interpolation for densities.

Table 5

The Correlation Coefficients, Coefficients of Determination, and Level of Variation Explained and Not Explained by the Third Order Trend Surface Analysis of Depth, Water Equivalent and Density

Parameter	Correlation Coefficient	Coefficient of Determination	Variation Explained by Surface	Variation Not Explained by Surface
Depth	0.43	0.19	49.3%	21.4%
Water Equivalent	0.35	0.12	43.4%	31.8%
Density	0.34	0.11	41.5%	32.6%

Table 6

The Mean, Standard Deviation, Coefficient of Variation and Sample Size for Snow Depth (cm), Elizabeth Basin Snow Survey, Feb. 21-27, 1979

Landscape Type	Sample Size	Mean Depth	Standard Deviation	Coefficient of Variation
Basin	526	100.90	66.67	61.23
Lake	129	31.46	20.97	66.44
OLW	216	126.90	60.87	47.97
CLW	107	146.62	41.11	28.04
Tundra	70	77.46	60.44	78.03

Table 7

The Mean, Standard Deviation, Coefficient of Variation and Sample Size of Water Equivalent (cm water) for Elizabeth Basin Snow Survey, Feb. 21-27, 1979

Landscape Type	Sample Size	Mean W.E.	Standard Deviation	Coefficient of Variation
Basin	526	26.26	19.95	75.97
Lake	129	8.98	11.43	127.28
OLW	216	33.64	20.54	61.06
CLW	107	34.46	14.09	40.89
Tundra	70	22.40	17.06	76.16

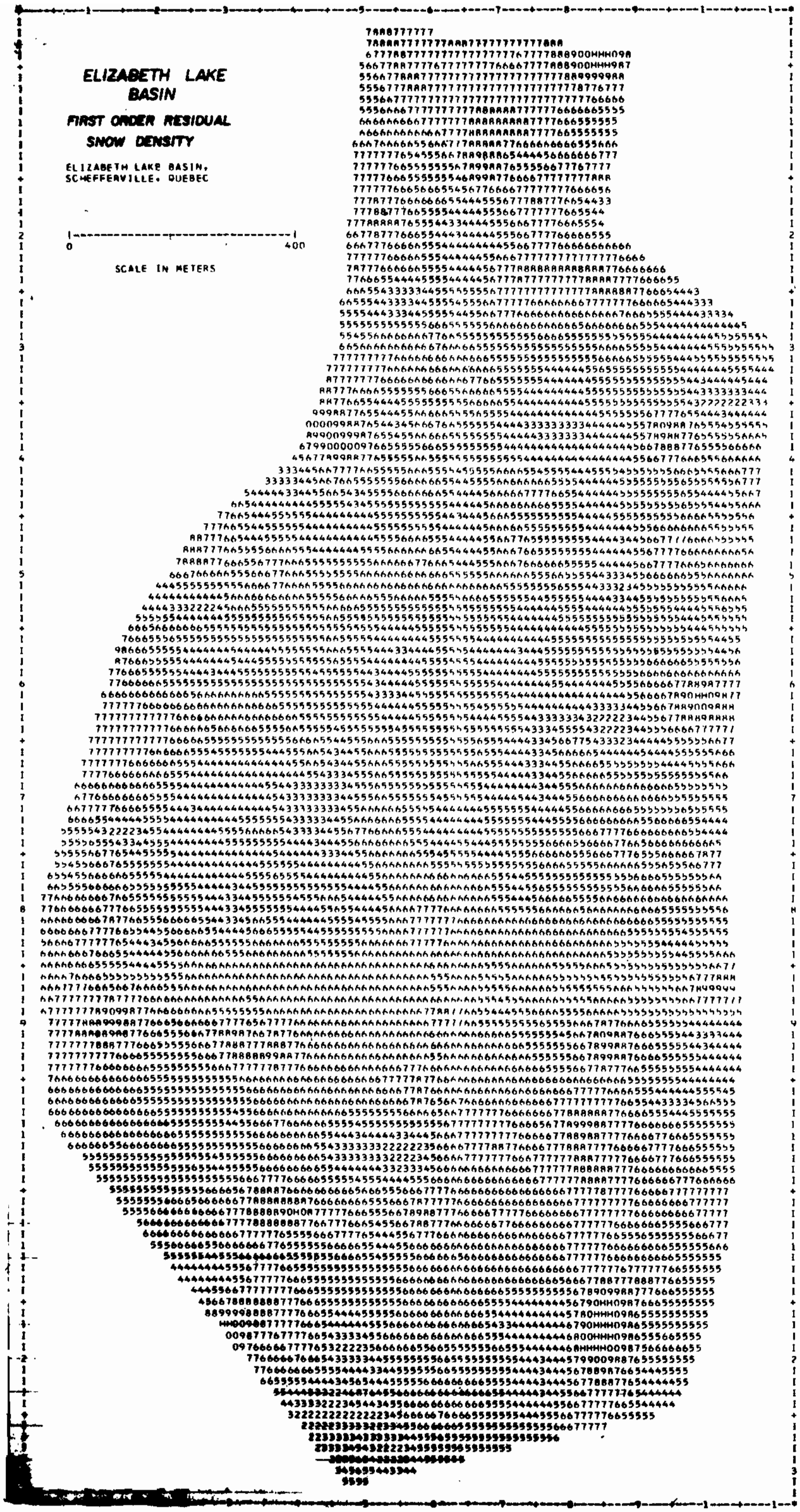

Figure 12. Residuals from first order trend surface, densities.

26.26 cm of water and an average density of 0.275 g cm^{-3}. Relatively, the greatest variability at the basin level (coefficient of variation 75.97%) occurred in water equivalent, least in density (29.45%).

The four landscape units of the basin appear to be markedly different in terms of depth. Peak mean depth (146.62 cm) occurred in CLW with a mean of only 31.46 cm on the lake, less than half the next shallowest area, Tundra (77.46 cm). However the highest coefficience of variation (78.03%) occurred in the latter, the lowest (28.04%) in CLW.

In terms of water equivalent (Table 7), the rank order of the landscape units in terms of the mean remains the same with highest values in CLW and lowest on the lake. However, although Lake and Tundra remain distinct, the difference between OLW and CLW is reduced reflecting higher densities in the former. Similarly, relatively low densities on the Lake result in a more marked difference between the shallower two of the landscape units, Tundra and Lake. There is a change in rank in the coefficient of variation column for water equivalent, the two tree-covered units, CLW and OLW respectively, remain least and second least in terms of variability but the Lake is appreciably more variable than Tundra. This last presumably indicates that on the Lake, the distribution includes shallow depths in association with low densities and deep areas which are characterized by high densities. The coefficient of variation can be greatly influenced by a few extreme values. All coefficient of variation values for water equivalent are higher than those for depth except Tundra.

Density exhibits the lowest relative variability in all cases (Table 8). The coefficient of variation is lowest on the lake, followed by CLW, Tundra and OLW. Tundra shows the highest mean values followed by the Lake, OLW and CLW. It is interesting that variation in density of the Lake, which shows a highly variable snowcover in terms of depth and water equivalent, should be so low. In part, at least, this reflects special features of the evolution of snow on lakes which are discussed below.

The CLW is clearly characterized by the highest mean depth and it retains first place in terms of water equivalent despite recording the lowest density. It is the landscape unit which shows least relative variability for depth and water equivalent. OLW exhibits the second deepest snowcover, deeper than the two non tree-covered units but shallower than CLW. However it contains only slightly less water per unit area than CLW as a result of higher densities but the densities are highly variable.

Some similarities appear to exist between OLW and CLW and between Tundra and Lake. The latter pair are characterized by the lowest depths and water equivalents while the former have the lowest densities. Tundra is the most variable of all categories in terms of depth but the Lake is most variable in terms of water equivalent. The greatest difference between Lake and Tundra lies in the coefficient of variation for density in which Lake shows the least variability and Tundra second highest.

The frequency distributions are displayed in Figures 14, 15 and 16. The shift to the left of the mode (CLW→OLW→T→Lake) in the case of depth (Fig. 14) and water equivalent (Fig. 15) is the visual expression of a pattern of descending values from what might be conceived as the most tree covered to the least vegetated unit. The distinctive role of the lake in the frequency distribution for the region is apparent in all cases--Figure 17 shows the frequency distribution for land snowcover (CLW, OLW and Tundra) for comparison with the Basin values in Figures 14, 15 and 16. The measures of central tendency and dispersion for the land area as a whole, are shown in Table 9 for comparison with Tables 6, 7 and 8.

Analysis of variance showed that the snowcover of the four landscape units was distinct in terms of all three properties. The values listed in Table 10 show that the sample F values are well above tabled F values for the 99% level.

In the light of this, it was not surprising that t-tests on all possible pairs of landscape units, for each property, showed that the snowcovers were distinct at the 90% level except for OLW and CLW in terms of water equivalent. This appears reasonable in the light of similarities between means, standard deviations and coefficients of variation for these cover types (Table 7).

Table 8

The Mean, Standard Deviation, Coefficient of Variation and Sample Size of Snow Density (g cm^{-3}), for Elizabeth Basin Snow Survey, Feb. 21-27, 1979

Landscape Type	Sample Size	Mean Density	Standard Deviation	Coefficient of Variation
Basin	526	0.275	0.084	29.45
Lake	129	0.296	0.068	22.97
OLW	216	0.263	0.079	30.04
CLW	107	0.241	0.066	27.38
Tundra	70	0.318	0.092	28.93

Table 9

The Mean, Standard Deviation, Coefficient of Variation and Sample Size for Depth, Water Equivalent and Density of the Land Portion of Elizabeth Basin Snow Survey, Feb. 21-27, 1979

Snow Parameter	Mean (n=397)	Standard Deviation	Coefficient of Variation
Depth (cm)	123.25	60.60	49.17
Water Equivalent (cm water)	31.89	18.88	59.20
Density (g cm^{-3})	0.268	0.083	30.97

Table 10

Analyses of Variance: F and Tabled F Values

Snow Parameter	Sample F	$F_{0.05}$	$F_{0.01}$
Depth	103.30	2.37	3.78
Water Equivalent	50.92	2.37	3.78
Density	14.87	2.37	3.78

Table 11

Regression Analyses Between Depth and Water Equivalent for the Basin and the Four Landscape Types

Landscape Type	n	Correlation Coefficient	Coefficient of Determination	Regression Equation	Significance Level
Basin	526	0.80	0.65	y=2.68x+30.42	0.00001
Lake	129	0.38	0.15	y=0.51x+24.69	0.00001
OLW	216	0.75	0.57	y=2.23x+50.93	0.00001
CLW	107	0.49	0.24	y=1.42x+97.99	0.00001
Tundra	70	0.85	0.72	y=3.02x+10.30	0.00001

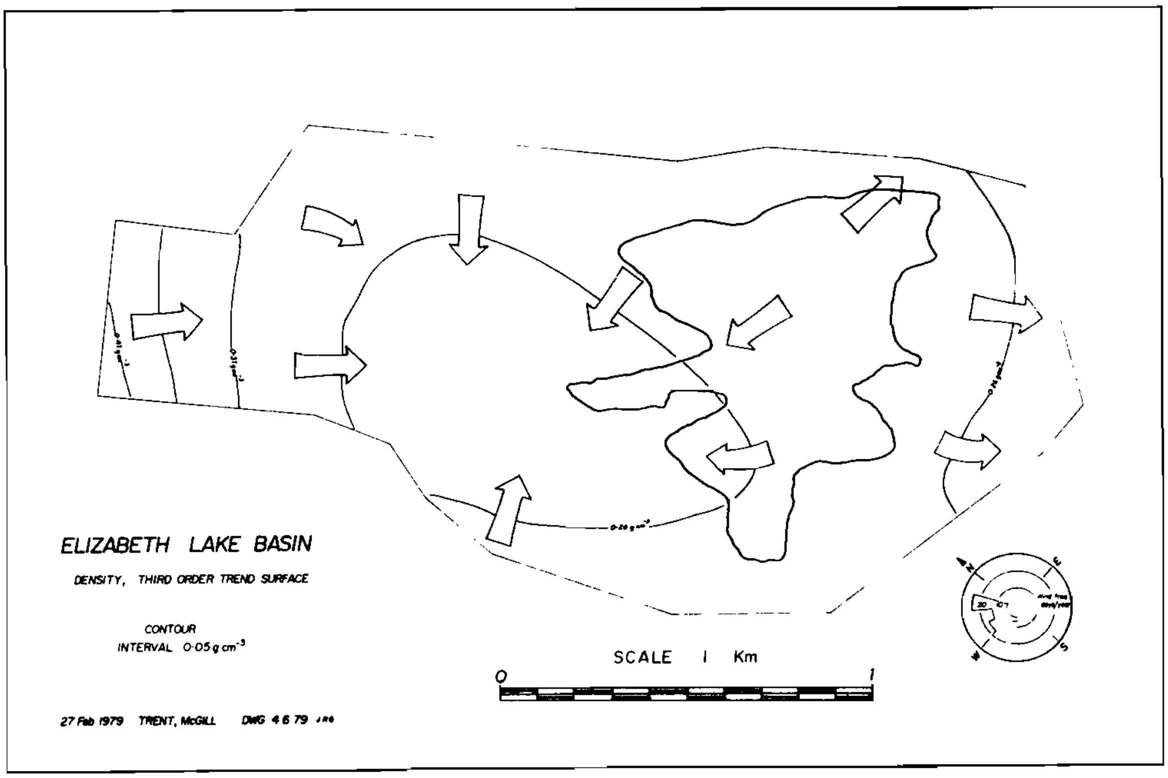

Figure 13. Third order trend surface, densities.

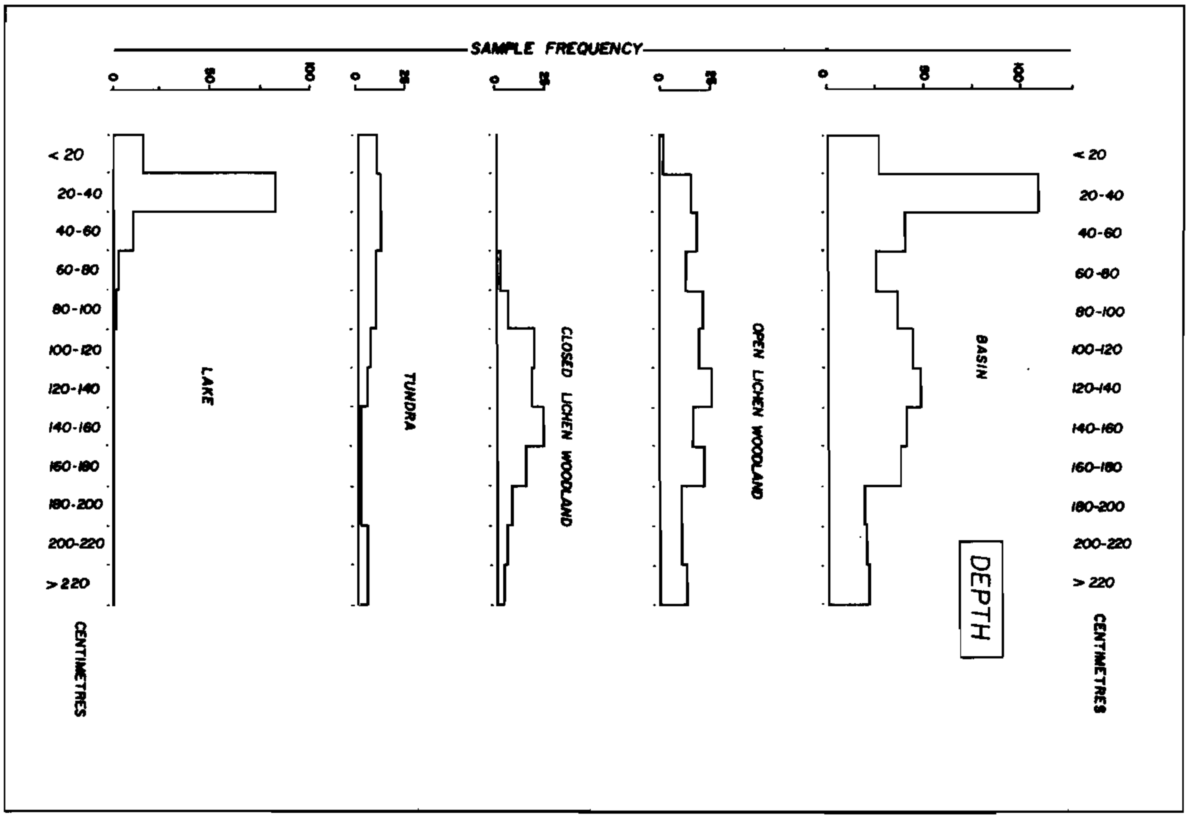

Figure 14. Frequency distribution for snow depths.

The fact that the pair, OLW and CLW, are similar in some respects is interesting in that it suggests that they might be treated together for some purposes. Their relative similarity, in terms of water equivalent, is particularly important for runoff prediction snow survey work as it suggests that the two tree-covered landscape units might be treated as one.

Regression analyses of depth and water equivalent, which are cited in the literature as important aides in snow surveying (high correlations mean that the expenditure of effort necessary in obtaining water equivalents can be reduced), cast some light on this (Table 11). The best relationships exist in Tundra and OLW, the worst on the Lake.

Stratigraphic profiles from each of the landscape units exhibited markedly different features but the sites concerned, of necessity, could not be considered to be a random sample.

PRELIMINARY CONCLUSIONS

1. The procedures used for calculating sample size, for allocating sample sites and for locating those sites in the field proved satisfactory. However the variability of snowcover encountered was such that it was possible to achieve a standard error of only 5.67 cm (depth) rather than the 2.54 cm which was the objective of the survey. The standard errors for water equivalent and density, for the basin as a whole, were 1.70 cm water and 0.007 g cm^{-3} respectively.

2. Analysis of variance suggested that the four 'landscape' units selected (Open Lichen Woodland, Close Lichen Woodland, Tundra and Lake) developed distinctive snowcovers in 1978-79. However, t-tests suggest that the means for OLW and CLW, the two tree-covered units, were not distinct in terms of water equivalent. If it is normal for OLW and CLW to be similar in terms of water equivalent, it is not necessary to differentiate between them in surveys designed for hydrologic purposes.

3. At the time of the survey, the snowcover of the landscape units selected had the following summary characteristics:-

OLW - relatively deep, relatively high water equivalent with relatively low variability for both properties; relatively low but highly variable density.

CLW - greatest depth and highest water equivalent with lowest variability of those properties; lowest density with relatively low variability of density. This is the most homogeneous snowcover type.

TUNDRA - relatively low, but highly variable depths relatively low water equivalent with relatively low variability of that property; higher, but relatively variable density. This is the most variable, least homogeneous of the snowcover types.

LAKE - Lowest snow depths, but relatively variable depths; lowest water equivalent, but highly variable; relatively high density with lowest variability of density.

These characteristics are summarized in Table 12 in which the magnitude and relative variability (coefficient of variation) are ranked high→low, 1→4.

It is interesting to note that the pairs OLW and CLW and TUNDRA and LAKE are juxtaposed in rank order in all columns except for relative variability of density. The density patterns produced the SYMAPS with least contrasts. Despite this juxtaposition, the paired units remained distinct except for the case cited above.

4. In terms of water storage, it is important to note that the tree covered units occupied 65% of the basin but contained over 80% of the water equivalent present as snow. This does not take into account snow incorporated into the ice sheet (see below).

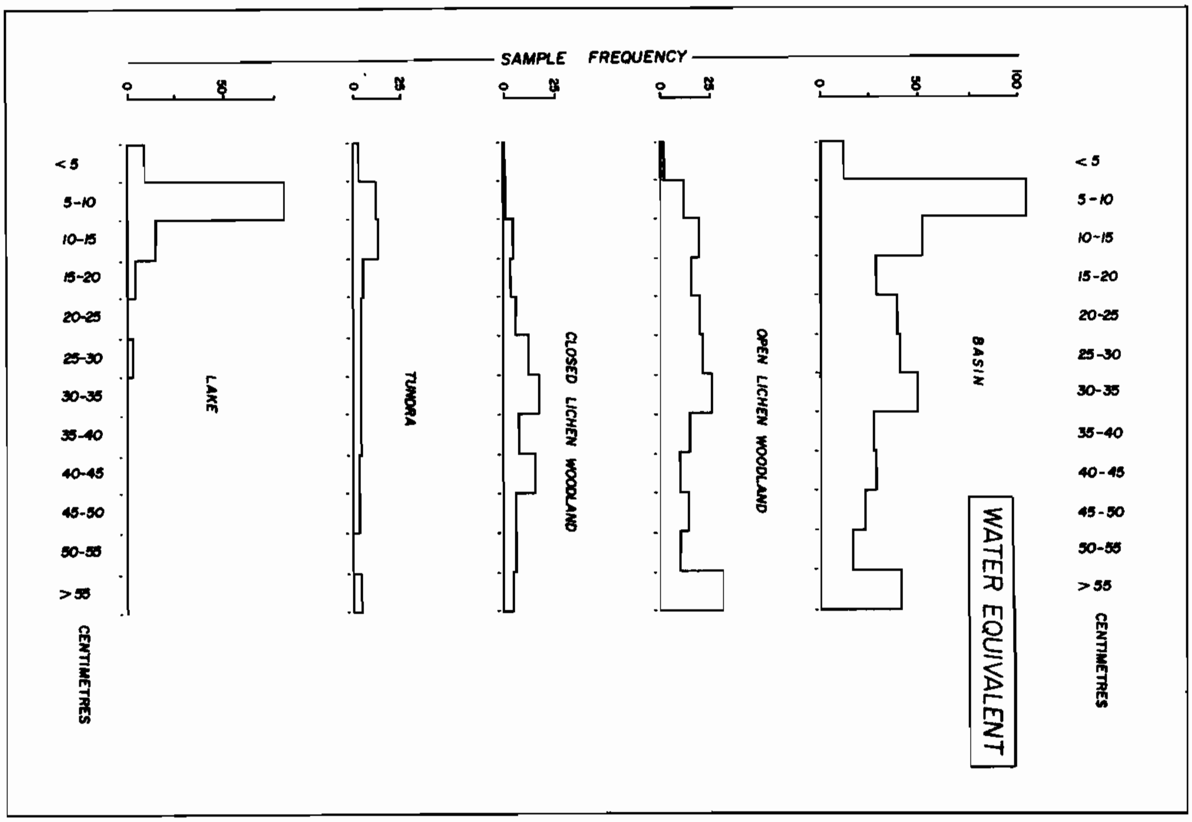

Figure 15. Frequency distribution for water equivalents.

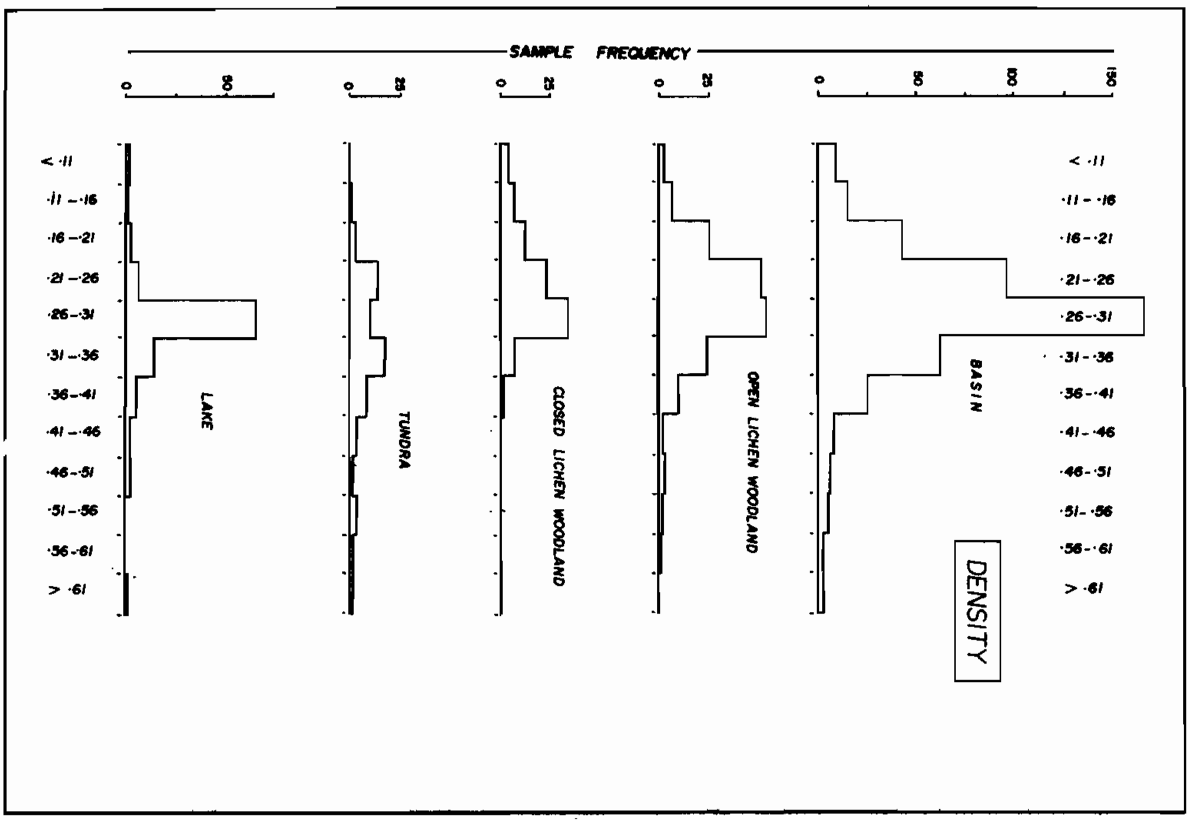

Figure 16. Frequency distribution for densities.

Table 12

Ranking of Magnitude and Variability of Snowcover Properties

Landscape Type	Depth Magnitude	Depth Relative Variability	Water Equivalent Magnitude	Water Equivalent Relative Variability	Density Magnitude	Density Relative Variability
OLW	2	3	2	3	3	1
CLW	1	4	1	4	4	3
Tundra	3	1	3	2	1	2
Lake	4	2	4	1	2	4

5. Granberg (1978) develops the important point that terrain roughness (including vegetation cover), which controls the wind-induced pattern of snow accumulation, changes during the accumulation season. The accumulating snow smoothens minor irregularities which inhibit drifting snow early in the season. In his relatively open study area, he conceives of an early season of fairly even snow distribution, a transitional season in which some areas have been smoothed while others remain irregular and a final phase where drift transport is least inhibited. Spatial variability is greatest in the second phase. It is to be expected that spatial variability of land snowcover will vary over time for these and other reasons, including areal differences in metamorphism. Thus the timing of a survey and the nature of the winter concerned have to be taken into account when generalizing about the snowcover of landscape units. This particular winter had the second highest snowfall on record for the Schefferville area (records provided by McGill Sub-Arctic Research Station). The measurements made represent the third of Granberg's phases so that they can reasonably be used as a basis for assessment of peak, pre-melt, snowcover conditions in the area.

6. In terms of generalizing from the small study basin to the general area in which Elizabeth Lake lies, it is interesting to note that the approximate proportions of the selected landscape units in the drainage basin of Knob Lake (Adams and Findlay,1960), which occupies 34.95 km^2 of the Labrador Trough are (with Elizabeth Basin values in parentheses), Lake 23% (21.73), OLW 20% (40.11), CLW 10% (25.03) and Tundra 47% (13.12). The differences in each category except Lake reflect in part the under-representation of ridges in a single, self-contained, basin as distinct from a drainage area which, like the Labrador Trough itself, contains a series of ridges and valleys. Also,differences in criteria used to select vegetation types limit the validity of comparison between these two surveys and the earlier samples were not as statistically sound.

It is interesting to note that surveys of depth and water equivalent in the Knob Lake catchment area in two winters (Adams *et al.*,1966) do suggest that Tundra and Lake are distinct (shallow and variable snowcover) from each other and from tree-covered landscape units but that OLW and CLW are similar in terms of both properties. This earlier study suggests that OLW contains a proportionately *higher* amount of snow in terms of water equivalent.

7. This paper focuses on relationships between particular easily recognizable landscape types and snowcover. The landscape units were defined in terms of vegetation characteristics. It is clear,however,that there are other controls of snowcover in the basin including topography, altitude, surface roughness (due to factors other than vegetation), aspect etc. Often effects of such controls involve interplay with wind. The trend surface maps displayed here hint at some of these controls, including up-wind and down-wind effects in a topographic basin. These aspects of the snowcover will be the subject of further study as will patterns *within* the landscape units including 'edge effects'. With regard to these last, it is worthy of note that wind-induced distributions might be expected to be different in the case of a gradation of increasing roughness (e.g., Lake→Tundra→OLW→CLW) than in a case where two very distinct landscape roughness types (e.g., Lake→CLW) are juxtaposed in an upwind-downwind sequence. For surveys of this type, trend surface analyses have the advantage of reducing local noise and indicating overall trends

based on the complete set of data. As higher trends are sought, the map surfaces come closest to trends that exist in reality.

8. The lake, which represents a very significant landscape unit within the region concerned, provides a very distinctive environment for snowcover evolution. The nature of this environment affects the properties of snowcover present at the time of the survey and the areal and temporal significance of the results of the survey.

It has been pointed out that the ice cover of a lake does not simply provide a particularly 'open' landscape unit upon which a snowcover can develop. Snow on lakes is subject to marked redistribution, including deflation, as would be the case in a similar extremely flat open space on land, but it is also affected by slushing when the snow load depresses the floating ice sheet below the hydrostatic water level. Also, its stratigraphic evolution is affected both by the slushing process and by the presence of the lake body, as a heat source, beneath the ice (Adams and Prowse,1978).

In terms of spatial distribution, Adams and Prowse (1978) suggest that the extremely low surface roughness of a lake surface results in particularly marked upwind-downwind, margin-centre, trends of snow depth and water equivalent but that this pattern is periodically destroyed by slushing. The slushing process has greatest effect in the deeper snow areas. Thus a temporal pattern of alternating phases of marked relative variability (associated with pronounced spatial trends), and phases of lower variability (and less marked spatial trends) can be envisaged. The pronounced margin-centre patterns of snow distribution on lakes reflect the fact that "edge effects" (see item 7, above) are probably more marked for this landscape unit than for the other 'units' used in this study.

In terms of snow stratigraphy, the slushing removes the lower layers of the pack leaving only recently fallen snow. Thus a snow pack which has been subject to slushing might be expected to exhibit generally lower densities and possibly a lower range of densities. Incorporation of snow into the ice sheet, which results from the slushing process, means that the snow pack present on a lake at any particular time will not represent all snow received by the lake even when deflation has been taken into account. In the Schefferville area, the amount of snow involved in this process can be considerable. In 1964-66, it amounted to close to 10% of all snow received in the catchment area of Knob Lake--a very much higher proportion of snow actually received by the lakes in that catchment area (Adams et al.,1966; Adams and Rogerson,1968).

It was pointed out in the discussion of frequency distribution that the lake snowcover in this survey was particularly distinctive. The Lake recorded distinctly lower snow depths and water equivalents than any of the other landscape units (for example, the mean water equivalent for Lake snowcover was less than one half of that of Tundra, Table 7). Also the Lake had the highest variability in terms of water equivalent and the second highest in terms of depth. The Lake snowcover of the time of the survey was therefore remarkedly shallow and was quite variable. This suggests that a good deal of slushing had occurred but that there had been time for further redistribution of snow since the last slushing event. Tests for spatial trends would be expected to show relatively marked patterns. The density of snow on the Lake was relatively high (Table 8), although not so high as Tundra, but with a low coefficient of variation. This, also, suggests that slushing had not taken place recently.

Table 13

Comparison of Landscape Types, with the Lake Snowcover Including the Snow Incorporated Into the White Ice

Landscape Type	Mean Depth	Standard Deviation	Coefficient of Variation
Basin	100.9	66.67	61.23
Lake	48.8	20.77	42.48
OLW	126.90	60.87	47.97
CLW	146.62	41.11	28.04
Tundra	77.46	60.44	78.03

At the time of the survey, the mean thickness of white ice on the Lake was 20.65 cm with a standard deviation of 13.82 cm (coefficient of variation 67%). Adding the white ice depth to snow depths on the assumption that it represents an equivalent depth of snow produces the pattern shown in Table 13. It can be seen that, even with the addition of snow incorporated into the ice sheet, the Lake remains in a very distinctive, shallow, snowcover type. This presumably reflects the fact that the Lake is a large, compact, open space whereas the next most open case, Tundra, is much less smooth and is made up of a number of separate areas of Tundra. Deflation from the Lake must be an important process, more important than in the case of Tundra.

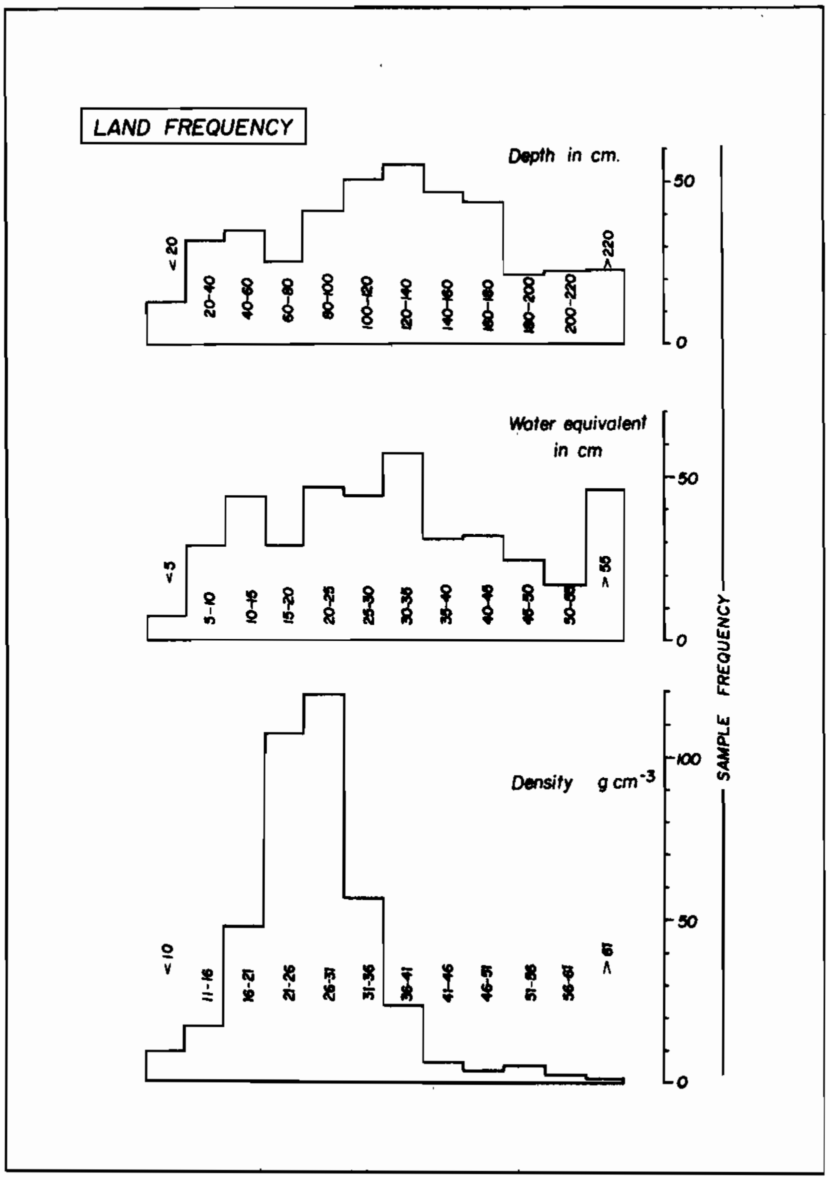

Figure 17. Frequency distribution for land area only.

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