

THE DEVELOPMENT OF A COMBINATION SLOPE MAP AND ITS  
APPLICATION TO THE STUDY OF LAND UTILIZATION  
IN SELECTED AREAS OF MANITOBA

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A Thesis

Presented to

The Faculty of Graduate Studies and Research

The University of Manitoba

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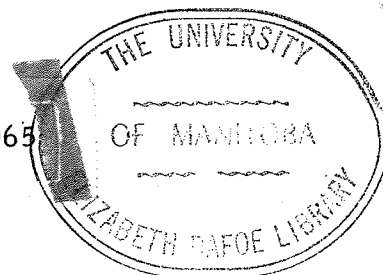
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of the Requirements for the Degree  
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## CHAPTER I

### INTRODUCTION

The topographical map presents much detailed, especially hypsometric information about terrain. It is, however, highly selective in what it shows, and often the detailed information that is given may not be in the desired form for direct use in geographical investigations. Particular elements of terrain, e.g. slope gradient, are important in studies of land-use, soil erosion, irrigation, flood control, transportation, economic planning and other aspects of human geography.

Sometimes, special methods of depicting terrain are required by geographers. The increasing demand for these special maps in varied geographical investigations has stimulated a search for more accurate, complete or effective representation of surface characteristics. In modern cartography, photographic and lithographic techniques have made valuable contributions to the search.

Concerning the relationship of human activities to relief, slope is one of the most influential elements. Therefore, the methods of slope determination and representation on maps have been the subject for much research, particularly by American geographers. The calculation of gradient between consecutive contours on a topographic map is easy, but the determination of average steepness of slopes and their representation on maps for areas of complicated relief requires much experimentation and critical analysis.

Slope analysis should be based on an objective or arbitrary system, applying methods such as random sampling or grid or uniform interval sampling. However, the choice of assessment of data completely depends upon one's purposes and propositions.

## The Present Techniques of Slope Representation

In this thesis, the primary interest is the representation of the form of land on maps, not the methods of calculating average slope. Nevertheless, the basic unit of land form is the slope. Up to now, many techniques of average slope representation have been evolved by geographers. These are reviewed below.

### 1. Representation by Hachures.

It was early recognized as desirable to indicate all steep slopes on military maps. The idea of taking the line oriented in the direction of maximum slope and thickening it according to the surface gradient is attributed to Major G. J. Lehmann of the Saxon army.<sup>1</sup> In this method the slopes are indicated by parallel lines drawn perpendicular to the direction of contours. There should be constant frequency of lines, the thickness of each being proportional to the slope gradient and the spaces between lines therefore inversely proportional to the same. The ratio of the thickness of the lines to the space between each line should be as the angle of slope to the difference between that angle and 45 degrees, for a slope over 45 degrees is shown entirely black. The thickness of the lines can be mathematically determined as follows:

$$L : i = X^\circ : 45^\circ - X^\circ$$

Where L = width of hachure line,

i = width of interval between the lines,

$X^\circ$  = the angle of slope.

<sup>1</sup> Cited by Captain H. G. Lyons, 'Relief in Cartography', Geography Journal, vol. 43, No. 3, 1914, pp. 246.

From the frequency of contour lines, the angles of slope can be determined, and hachures of various thicknesses inserted by hand.

The advantage of the Lehmann system of hachuring is that on such a map mountains can be visualized even by untrained persons. Theoretically, the angle of slope can be measured, but actually it cannot be read because of the difficulty of measuring line thickness. The hachure map is very laborious to construct, too. In modern times, hachures have been little used in presenting slope information, but constitute a visually effective technique.

An alternative hachure technique of maintaining line thickness, but varying line frequency according to gradient has also been employed by cartographers. The frequency is directly proportional to gradient. This technique has the same visual effect.

## 2. Representation by Choropleths.<sup>2</sup>

The tinted or shaded choropleth map is a very common technique used in showing average slopes. It shows the areal distribution of different groups or categories of slopes, and so by using a planimeter, the actual magnitude of each slope group can be evaluated.

E. Raisz and J. Henry<sup>3</sup> divided the large scale topographical map into small 'regions' within each of which the contour lines were approximately

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<sup>2</sup> E. Raisz, General Cartography, pp. 246 (1st ed. 1938, New York), emphasizes that the term choropleth need not be limited to administrative divisions, but that a map divided into squares for which a density could be calculated and then tinted or shaded would also be a choropleth map. He suggested that the term 'demopleth' be used for those maps based on administrative divisions.

<sup>3</sup> E. Raisz and J. Henry, 'An Average Slope Map of South New England', Geographical Review, vol. 27, 1937, pp. 467-72.

uniformly spaced. Six slope categories were chosen, according to the average density of the contour lines; with these as a guide, each region was carefully examined and classified. When the slope regions had been demarcated on the large-scale topographic sheets, their boundaries were transferred to small-scale maps, and choropleths were drawn.

Later, E. Raisz named this type of map a 'Slope-category map'.<sup>4</sup>

This system emphasizes detail and shows the spatial associations of different slopes, as well as depicting important minor topographic features.

W. Calef and R. Newcomb<sup>5</sup> constructed an average slope map of Illinois, by following in general principles the Raisz and Henry method, though using the Wentworth equation<sup>6</sup> instead of delimiting areas of uniform contour spacing. Four slope classes were defined and represented by distinctive tints.

### 3. Representation by Isopleths.

A. N. Strahler introduced two types of slope maps, based on isotangents and isosines, in 1956.<sup>7</sup> A large number of slope values, in degrees, were converted into the values of tangent and sine, and these values were plotted at control points. Gradients can be obtained either by measuring

<sup>4</sup> E. Raisz, 'Principles of Cartography', pp. 87 (New York 1962).

<sup>5</sup> W. Calef and R. Newcomb, 'An Average Slope Map of Illinois', Annals of the Association of American Geographers, vol. 43, 1953, pp. 304-16.

<sup>6</sup> C. K. Wentworth, 'A Simplified Method of Determining the Average Slope of Land Surfaces', American Journal of Science, series 5, vol. 20 (New Haven, Conn., 1930). Wentworth's formula for average slope determination is  
Average number of contour crossings per mile X contour interval

<sup>7</sup> A. N. Strahler, 'Quantitative Slope Analysis', Bulletin of the Geological Society of America, vol. 67, pp. 571-596 (New York 1956).

contours on large-scale topographic maps, or by using an Abney Level in the field. With the values of tangent and sine on the base map, series of isotangents and isosines respectively were interpolated.

Furthermore, a percentage frequency distribution histogram was constructed and statistical parameters were deduced by measuring the areas between successive isotangents or successive isosines with a polar planimeter.

These two types of slope maps, which have a large potential value in engineering and military applications, have not been widely applied in geography.

Coefficient of Land Slope. E. Raisz developed a method of establishing an exact 'coefficient of land slope'.<sup>8</sup> The chosen topographic map is covered with rectangles whose dimensions are determined, arbitrarily, according to the degree of homogeneity of terrain; the more uniform the slope the larger the rectangles can be. Each rectangle is divided into areas of approximately constant slope by counting contour frequencies. Then the total area of all slope units within each category is measured with a planimeter. A horizontal line is drawn proportional in length to the total area of the rectangle, and the sum totals of areas in each slope category are represented to scale along this line (starting with the gentlest slopes at the left end). A series of connected lines in a slope sequence is drawn, each at the angle of slope corresponding to the appropriate vertical rise per mile, inclusive of the maximum slope occurring in the rectangle. The area bounded by the horizontal, vertical and connected sloping lines provides a coefficient of

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<sup>8</sup> E. Raisz, 'General Cartography', pp. 273 (1st ed. New York, 1938).

Also see F. J. Monkhouse and H. R. Wilkinson, 'Map and Diagrams', pp. 107, figure 41 (2nd ed. 1963).

slope for the rectangle for which it has been drawn. This is calculated by simple geometry. Completely flat land will have a coefficient of zero. After the determination of coefficients for all rectangles, their respective values are plotted at the geometrical centres of the grid units; then selected isopleths can be drawn.

The Flatland-Ratio Map was introduced by E. Raisz,<sup>9</sup> and can be prepared in the following way. On the topographic sheet, used as base map, the land which is not too steep for farming is delimited, and described as 'flatland'. (The steepness of slope which can be farmed depends on local agricultural practices.) The map is divided up into small rectangles, in the geometric centres of which the respective percentages of flatland are plotted. Isopleths are then inserted.

#### 4. Representation by Dots.

A. H. Robinson<sup>10</sup> produced a quantitatively accurate relief map from areal slope data. He divided the topographic sheets into squares each representing an area of 0.01 square miles. The average gradient within each square was estimated, and one dot for each degree of slope was placed within it. The dots were not placed symmetrically within each square; their positions were determined by reference to the contours on the topographic map.

In theory, the map is quantitatively precise, for the dots are countable. At the same time, the variation in relative dot density from one area

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<sup>9</sup> E. Raisz, 'General Cartography', pp. 274 (ed. 1938).

<sup>10</sup> A. H. Robinson, 'A Method for Producing Shaded Relief from Areal Slope Data', Surveying and Mapping, vol. 8 (Washington, 1948). Cited by F. J. Monkhouse and H. R. Wilkinson, Maps and Diagrams, pp. 107 (2nd ed. 1963).

to another gives an effective visual impression; but the map cannot give the areal values of slope units.

### 5. Slope Zone Technique.

The slope-zone device was first suggested in 1951 by O. M. Miller,<sup>11</sup> and maps were developed in 1960.<sup>12</sup> The aim of this technique is to emphasize slope rather than elevation, and to divide the map surface into a series of zones, which would reveal the detailed character of landforms. The zones can be reproduced in subdued tints. Miller and Summerson used the concept of A. Wood's fourfold classification of slope elements in the development of a hillside<sup>13</sup>: 'waxing slope', 'free face', 'constant slope' and 'waning slope'. In particular, they searched for a trigonometrical function of slope that would provide a gradient value that could be used to delimit valley floors from their sides. They considered the functions  $(1-\cos x)$ ,  $x$ ,  $\sin x$  and  $\sqrt{\sin x}$ , where  $x$  is the angle of slope, and divided the ranges of values of each into 8 equal parts. Eventually, only four equal parts — separated by slope values of  $3^{\circ}35'$ ,  $14^{\circ}24'$ ,  $34^{\circ}14'$  — out of eight obtained from the  $\sqrt{\sin x}$  function were chosen as the most suitable, thus giving four slope zones ( $0^{\circ} - 3^{\circ}35'$ ,  $3^{\circ}35' - 14^{\circ}24'$ , etc.). It is claimed that these four zones coincide with Wood's four slope elements. For more detailed maps, eight slope-zones categories can be adopted.

The compilation of a slope-zone map is easy if the region is covered with large-scale contoured topographic maps. The tinted map of slope zones

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O. M. Miller, 'Relief on Maps and Models: Some Conclusions and a Proposal', The Ohio State University Research Foundation, Mapping and Charting Research Laboratory, Technical Paper No. 151, 1951. Cited in 'Slope-Zone Maps'.

12 O. M. Miller and C. H. Summerson, 'Slope-Zone Maps', Geographical Review, vol. 50, 1960, pp. 196.

13 A. Wood, 'The Development of Hillside Slopes', Proceedings of Geologists' Association, vol. 53, pp. 128-40 (London 1942). Cited by O. M. Miller and C. H. Summerson in 'Slope-Zone Maps'.

may be reproduced to the intended scale without loss of detail or clarity, as was demonstrated by Miller and Summerson in the production of a slope-zone map of the Appalachians at a scale of 1:2,000,000.

This kind of technique gives an excellent visual impression of the salient characteristics of slopes, and is particularly suitable for the morphological study of landscapes and in the determination of physiographical regions.

#### 6. Slope Representation by Combined Techniques.

F. E. Elliot<sup>14</sup> introduced a technique of portraying slope gradients and relative relief on one map. He used a fine grid of squares to calculate values of relative relief. After these had been plotted, isopleths were drawn to show the spatial distribution of relative relief. Elliot then shaded the relative relief categories in various horizontal lines. A contour-spacing guide of the same contour map base was employed to secure the values of average slope, and three categories were recognized and vertical line-shaded. The superimposition of these two maps produced twelve composite slope and relative relief regions, which were outlined by pecked lines with the obvious identification of different intensities of cross-shading.

R. M. Glendinning<sup>15</sup> applied a simple technique to express slope conditions by using arrows to show the direction and steepness of slope and pecked lines to indicate the change of slope, for superimposing on land-

<sup>14</sup> F. E. Elliot, 'A technique of presenting Slope and Relative Relief on One Map', Surveying and Mapping, vol. 13, 1953, pp. 473-78. Cited by F. J. Monkhouse and H. R. Wilkinson, Maps and Diagrams, pp. 112 (2nd ed. 1963).

<sup>15</sup> R. M. Glendinning, 'The Slope and Slope-Direction Map', Michigan Papers in Geography, vol. 7 (Ann Arbor, Mich., 1937). Cited by F. J. Monkhouse and H. R. Wilkinson in Maps and Diagrams, pp. 110 (2nd ed. 1963).



use and soil maps. This method can be used for correlating soil erosion, land suitability and slope.

#### 7. Graphic Representations.

J. O. Veatch has devised a scheme for the graphic comparison of slopes and developed some ideas for comparing land on the basis of the number and areal extent of significant land components, of which he recognized three, 'highland', 'lowland' and 'slopes'.<sup>16</sup> Data may be obtained for constructing graphs from contour maps either by linear traverse measurements or by actual areal measurement. The 'slopes' component consists of classes of slopes, based on ranges of gradient. The function of the graph is to integrate these separate slope classes by expressing them as a single continuous sloping line. This line, which represents the integration of the slopes, has a gradient that is determined by a number obtained by multiplying the percentage frequency of each class of slope by its respective average gradient and taking one-quarter of the summation of these figures. The graph is constructed in the following way. A square is drawn, a side of which is equal to the total slopespercentage distance on the graph. A value that is equal to one-fourth of the highest gradient value times 100 is assigned to the combined right vertical and basal sides of the square. This is the integrated slope number and is represented by an inclined line joining the horizontal line depicting 'highland' at the upper left hand corner of the square. The horizontal line representing 'lowland' is added to the lower extremity of the inclined line afterwards. The lengths of these appended lines are proportional to the respective proportions of 'highland' and 'low-

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<sup>16</sup> J. O. Veatch, 'Graphic and Quantitative Comparisons of Land Types', Journal of American Society Agronomy, vol. 27, 1935, pp. 505-510.

land' in the region.

The Clinographic Curve, first named by J. Hanson-Lowe,<sup>17</sup> shows the average gradient between any pair of contours. Its chief advantage is that it indicates both major breaks and sudden changes in the relief of any region, and it emphasizes uniform surfaces such as a peneplain.

Areas of land between pairs of successive contours are measured, and then represented by concentric circular zones. The average gradients between these pairs can be calculated, using the tangent function,  $\tan \theta$  (angle) =  $h/R-r$ , where  $\theta$  is the average gradient of land between two successive contours,  $h$  is the contour interval, and  $R-r$  represents the difference in length between the radii of the respective circles.

After all the values of slope angle have been calculated, a clinographic curve can be drawn, using the contour intervals as vertical components and inserting each section of average slope gradient between each two contours with a protractor. If the clinographic curve possesses gentle slopes, then a vertical exaggeration may be used, by increasing each angle by a constant factor.

The Mean Slope Curve introduced by A. N. Strahler,<sup>18</sup> is a device for showing mean slope gradient by a curve. First, the length of each contour line is measured, and the average length of each pair of successive contours is calculated. The area between these contours is measured with a plani-

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17 J. Hanson-Lowe, 'The Clinographic Curve', Geological Magazine, vol. 72, pp. 180-4 (London 1935).

18 A. N. Strahler, 'Hypsometric (Area-Altitude) Analysis of Erosional Topography', Bulletin of the Geological Society of America, vol. 63, 1952, pp. 1117-42.

meter. The average width of each intercontour area is obtained by dividing this area by the mean length of the two successive contours. For the area above the highest contour, the mean width between each pair of successive contours is replaced by half the length of the highest contour. The tangent of the slope angle can be derived by dividing the contour interval by the mean width of each pair of successive contours. Then the curve, consisting of several straight-line segments, can be plotted.

In Strahler's method, ground slope distribution with respect to height can be depicted for direct visual analysis.

Slope-Height Curve. It was produced by F. Moseley<sup>19</sup> who determined the average slope value between each pair of contours at regular intervals. From these he was able to construct a slope-height curve, on which the average slope value between each pair of contours in each region was depicted. Uniform slopes were represented as straight lines parallel to the vertical axis of the graph, concave slopes with a uniform change of gradient were revealed as straight lines inclined to the right, whilst convex slopes were shown as straight lines inclined to the left.

This method can be utilized for analyzing slope values directly measured in the field, or for mean slopes of intercontour areas obtained by either the Hanson-Lowe or the Strahler methods.

The Columnar Diagram of Slope compiled by A.T.A. Learmonth,<sup>20</sup> in 1948, consists of a series of parallel bars whose lengths are proportional to the percentages of land of various inclinations.

<sup>19</sup> F. Moseley, 'Erosion Surfaces in the Forest of Bowland', Proceedings of the Yorkshire Geological Society, vol. 33, part 2, No. 9, pp. 173-96 (Hull, 1961). Cited by in Maps and Diagrams, pp. 122 (2nd ed. 1963).

<sup>20</sup> A.T.A. Learmonth, 'The Floods of 12th August, 1948, in South-east Scotland' (circulated in manuscript form, 1951). Cited in Maps and Diagrams, pp. 110 (2nd ed. 1963).

## 8. Conclusion.

In all the methods described above, there are none that depict all types of slope information; in other words, every technique has its limitations. As a special technique, the slope map can emphasize what the compiler wants to show. So far, the few combined techniques of terrain representation can present more detailed and varied slope information than the others, therefore they are often more useful for geographical investigations.

In this thesis, a type of combined map and graph technique is proposed for presenting slope information for general use. It employs both choropleths and located line-graphs. The Raisz and Henry method was adopted for securing slope data from topographic sheets, because it can depict slope location in detail. The line-graph technique that is applied in this thesis broadly resembles E. Raisz's coefficient of land slope and J. O. Veatch's land components methods, but there are some important modifications that have been made with the aim of presenting more detailed slope information.

## CHAPTER II

### CONSTRUCTION OF THE COMBINATION SLOPE MAP

#### 1. Choice of a Suitable Map Scale.

In this thesis, the scale of topographic sheets chosen as base maps is 1:50,000, the most widespread of the large scale maps obtainable in Canada, though their publication is not completed yet. The 1:50,000 maps of Manitoba have been produced with air photographs taken mainly between 1947 and the early 1950's. These maps are regarded as accurate. Another large scale series of topographic sheets is at 1:25,000, but its coverage is limited to a few small localities in Manitoba, excluding the areas arbitrarily chosen in this study.

The contour interval of the 1:50,000 Canadian maps is almost always 25 feet, a value which enables much detail of the surface configuration to be depicted. Fortunately, this scale is sufficiently large to show the degree of detail desired as a basis for this work. Another advantage of this scale is that the land use details on air photographs can be plotted quite accurately.

#### 2. Size of Areas to be Studied.

Areas for cartographic analysis were arbitrarily chosen from an examination of topographic maps of types of terrain in Manitoba. Four areas were adopted for study, the size of each being between 60 and 100 square miles. Three areas lie astride the Manitoba Escarpment, but the remaining one extends from the northern margin of the Tiger Hills to